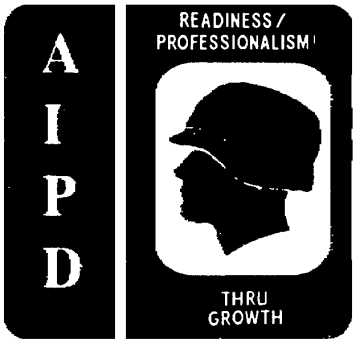
SUBCOURSE **EDITION**

MM0456 **7**

DC LOW FREQUENCY THERMAL MEASUREMENTS

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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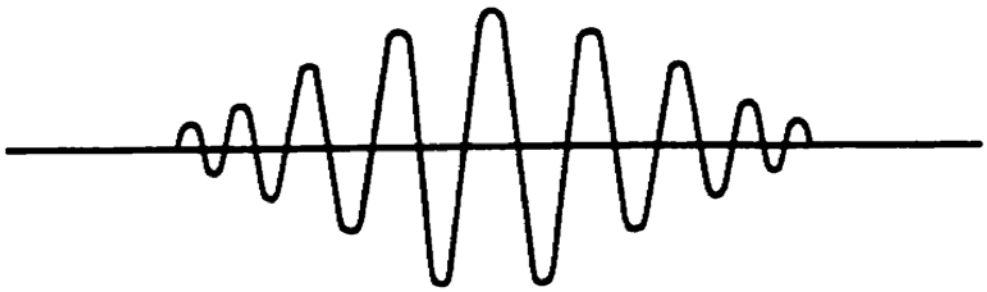

US ARMY CALIBRATION SPECIALIST
MOS 35H SKILL LEVELS 1, 2, and 3

PLEASE NOTE

Proponency for this subcourse has changed from Signal Center & School (SM) to Ordnance Missile & Munitions Center & School (MM).

DC LOW FREQUENCY THERMAL MEASUREMENTS

SUBCOURSE NO. SM 0456-7

US Army Signal Center and Fort Gordon
Fort Gordon, Georgia

Five Credit Hours

GENERAL

As a Calibration Specialist, you are aware of the many applications and extreme versatility of electronic voltmeters and ammeters. At one time or another, you have probably been afforded the opportunity to test the stated parameters of these instruments. Depending on the degree of accuracy required, you might have used any one of the several different calibration test sets to accomplish the task. This subcourse is devoted to two working standards currently in use by the US Army; the John Fluke Model 540B Thermal Transfer Standard used primarily in the calibration van, and the Ballantine Model 1600A/B Autobalance True RMS AC/DC Reference Standard used in the calibration laboratory. The subcourse is presented in three lessons, each lesson corresponding to a terminal objective as indicated below.

Lesson 1: THE THERMOCOUPLE

TASK: Describe and identify theory of a thermocouple used in the application of DC Low Frequency (DCLF) thermal measurements.

CONDITIONS: Given the information and illustrations about thermocouple theory relating to DCLF thermal measurements.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to at least 75 percent of the multiple-choice test covering theory and application of a thermocouple in DCLF thermal measurements.

Lesson 2: DCLF THERMAL TRANSFER STANDARDS

TASK: Describe the function and operation of each thermal transfer standard.

CONDITIONS: Given the information and illustrations about theory and applications relating to thermal transfer standards.

STANDARDS: Demonstrate competency of the task skills and knowledge by correctly responding to at least 80 percent of the multiple-choice test covering theory and application of thermal transfer standards.

Lesson 3: DCLF REFERENCE STANDARDS

TASK: Describe the function and operation of each thermal reference standard and theoretically troubleshoot the 1600A Thermal Reference Standard.

CONDITIONS: Given the information and illustrations about theory and applications relating to DCLF reference standards.

STANDARDS: Demonstrate competency in task skills and knowledge by correctly responding to at least 80 percent of the multiple-choice test covering theory and application of thermal reference standards to include theoretical troubleshooting of the 1600A Thermal Reference Standard.

This subcourse supports, in part or in full, the following tasks:

Task Number	Task Title
113-574-5091,	Calibrate Thermal Transfer Voltmeter 540B
113-574-5092,	Calibrate AC Voltage Standard 745A
113-574-5093,	Calibrate AC High Voltage Amplifier 746A
113-574-5095,	Calibrate AC Ammeter Calibrator 250
113-574-5136,	Calibrate Thermal Converter 1395-1

TABLE OF CONTENTS

Section	Page
TITLE PAGE	i
TABLE OF CONTENTS	iii
INTRODUCTION TO DCLF THERMAL MEASUREMENTS	vi
Lesson 1: THE THERMOCOUPLE	1
Learning Event 1: Define and Identify the Theory of a Thermocouple	1
Learning Event 2: Describe Thermocouple Materials and Types	4
Learning Event 3: Describe Thermocouple Applications	9
Practice Exercise	14
Lesson 2: DCLF THERMAL TRANSFER STANDARDS	16
Learning Event 1: Describe the Function and Use of Model 540B Thermal Transfer Standard	16
Learning Event 2: Describe the Function and Use of Model 1395B Coaxial Thermal Converter	31
Learning Event 3: Describe the Function and Use of Model B7842 Thermal Converter	36
Practice Exercise	38
Lesson 3: DCLF REFERENCE STANDARDS	40
Learning Event 1: Describe the Model 1600A Thermal Reference Standard	40
Learning Event 2: Explain the Model 1600A Operation Modes	50
Learning Event 3: Describe the 1600A Circuit	55
Learning Event 4: Describe the NBS Thermal Voltage Converter Set	57
Practice Exercise	60
ANSWERS TO PRACTICE EXERCISES	62

*** * * IMPORTANT NOTICE * * ***

THE PASSING SCORE FOR ALL ACCP MATERIAL IS NOW 70%.

PLEASE DISREGARD ALL REFERENCES TO THE 75% REQUIREMENT.

Whenever pronouns or other references denoting gender appear in this document, they are written to refer to either male or female unless otherwise indicated.

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INTRODUCTION TO DCLF THERMAL MEASUREMENTS

If you were required to measure a given AC voltage, you would probably obtain an AC voltmeter which met the necessary requirements; accuracy, range and frequency response, and perform the measurement. This is the proper procedure for the majority of AC measurements, but there are always those instances where an AC voltmeter is not available, or there is not one which has the proper specifications. This is when you would revert to AC-DC transfer measurement procedures. Thermal transfer standards are used extensively to provide extremely precise low voltages and currents from DC to 1 GHz for calibration of such instruments as the Model 410C Electronic Multimeter, Model 887 Differential Voltmeter, and the Model 3490A Digital Voltmeter, and the Model 760A Meter Calibrator.

The purpose of this subcourse is to provide the calibration specialist with a working knowledge of the theory and use of the thermocouple, DCLF thermal transfer standards, and the DCLF reference standards.

LESSON 1
THE THERMOCOUPLE

TASK

Describe and identify the theory of a thermocouple used in the applications of DCLF thermal measurements.

CONDITIONS

Given the information and illustrations about thermocouple theory relating to DCLF thermal measurements.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to at least 75 percent of the multiple-choice test covering theory and application of a thermocouple in DCLF thermal measurements.

REFERENCES

None

Learning Event 1:
DEFINE AND IDENTIFY THE THEORY OF A THERMOCOUPLE

1. The thermocouple is perhaps the simplest of all primary measuring elements. In its simplest form it consists of two dissimilar electrical conductors joined at each end to form a continuous circuit, and electrically insulated from each other along their length between these two junctions. This thermocouple develops an electromotive force (EMF/voltage) when there is a temperature difference between the two junctions and a current will flow in the closed circuit. In practice, one of these, junctions is called the measuring (hot) junction and the other is called the reference (cold) junction. The power or current that is available from a thermocouple to drive a measuring device is quite small; however, this drawback has been largely overcome by the development of high-gain amplifiers, millivoltmeters, and galvanometers of improved sensitivity.

2. It has been stated that the power or current available from a thermocouple is quite small; but what type of current is it? The voltage available from a thermocouple is direct current (DC). This DC output to the measuring instrument is determined by the amount of current applied to the measuring junction regardless of whether it is DC or alternating current (AC). The thermocouple output is determined by the heat difference between the measuring and reference junctions. This heat difference is determined by the root mean square

(RMS) value of the applied AC input. Figure 1-1 is a diagram of a basic thermocouple. The AC input is applied to the measuring junction and the heating effect of this AC input causes the measuring junction to increase in temperature, thereby producing a DC output to the meter. Remember that an equivalent value of DC will produce the same temperature at the measuring junction as an equal value of RMS AC.

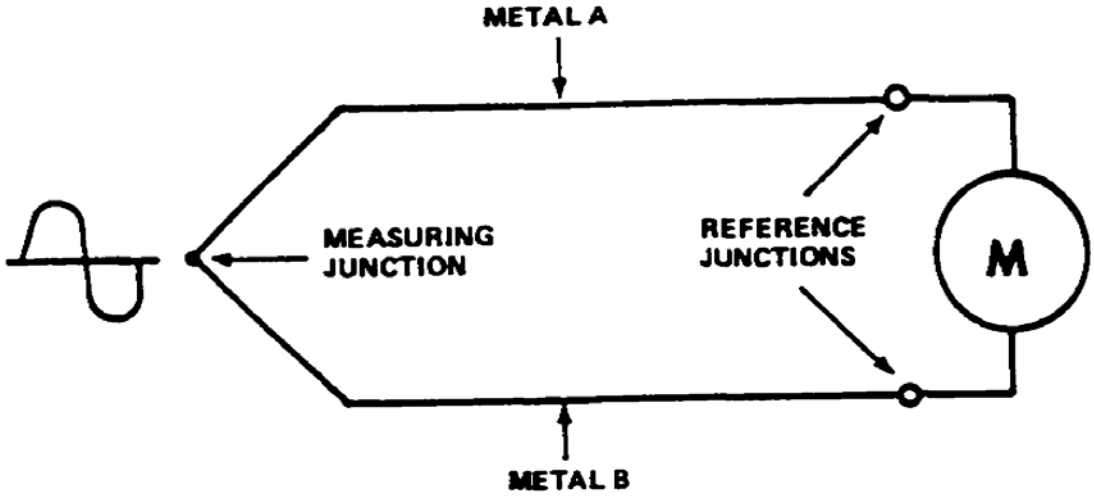
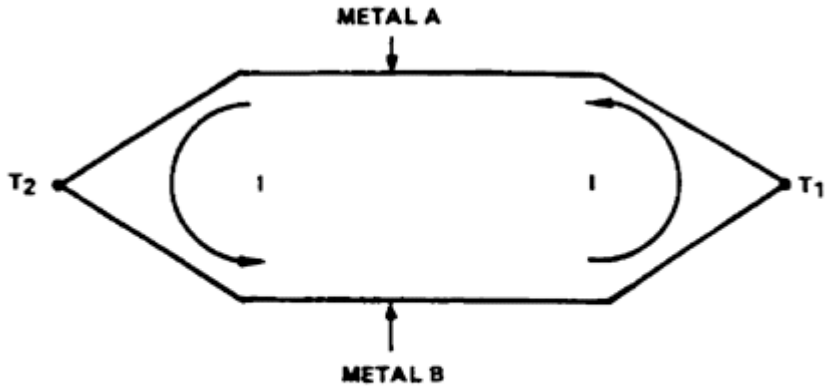


Figure 1-1. Basic thermocouple

3. Now we know that thermocouples produce a DC output when the measuring junction is heated; let's discuss some of the laws that are associated with thermocouples. We will not mention every law, but only those that will be of some concern to you and your use of thermocouples.

4. At the junction of two dissimilar metals, there exists an EMF known as the Seebeck effect, which is a function of temperature (fig 1-2). If the circuit is closed by another remote junction of the two conductors, another opposing EMF exists at the other junction. If these junctions are at the same temperature, the EMFs are equal and opposite, and no current flow will result. However, if one junction is at a higher temperature, the EMF at the hot junction will exceed that at the cold junction, and a current will flow, which is dependent on the resistance of the circuit. This current flow through a resistance involves a dissipation of energy in heating the conductor, or the current may be used to perform work. The electric energy derived from an absorption of heat at the hot junction and a rejection of heat at the cold junction, so that the device is a thermodynamic engine for the conversion of heat to electrical work.



NOTE: - T_1 AND T_2 ARE AT DIFFERENT TEMPERATURES CAUSING I TO FLOW

Figure 1-2. Seebeck effect

5. The operation is reversible, in the same sense that, if an electric current is forced through the circuit by a battery, heat will be absorbed at the cold junction and rejected at the hot junction. Under these conditions, the device functions as a refrigerator or heat pump. This phenomenon is known as the Peltier effect (fig 1-3).

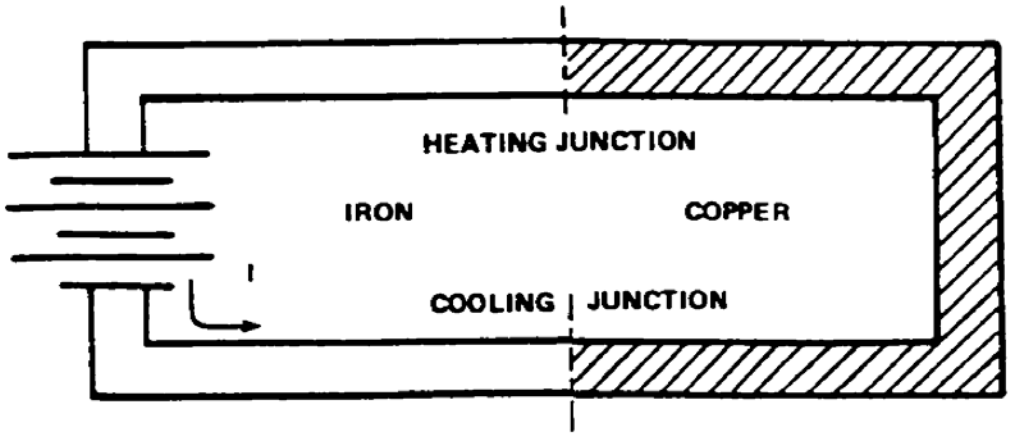


Figure 1-3. Peltier effect in a copper-iron junction

6. From thermodynamic reasoning, Lord Kelvin showed that the interrelation of the Peltier and Seebeck effects should lead to a linear relationship between temperature difference and EMF. However, experiments showed that the relationship is not linear. He demonstrated that there must be an EMF developed in a single homogenous (copper, silver, or aluminum) conductor whose ends are at different temperatures. This is the Thompson effect. It is associated with the thermal conduction of heat from the hot end of the conductor to the cold end.

7. If a third metal is introduced into the circuit, it may have both of its ends connected to one of the original metals. If the new connections are at the same temperature, equal and opposite EMFs will be developed, and there will be no change from the electrical condition of the original circuit. If the new intermediate metal joins the original pair, it is still true that the net EMF is not affected if its ends are of the same temperature. The proof of this statement involves reasoning based on the second law of thermodynamics, the Law of Intermediate Metals.

8. The Law of Intermediate Metals states that the algebraic sum of the thermoelectric EMFs (voltages) of a circuit composed of any number of dissimilar metals is zero if the circuit is at a uniform temperature throughout. There must be a difference in temperature between the two junctions in order for there to be a DC voltage output from the thermocouple.

Learning Event 2:
DESCRIBE THERMOCOUPLE MATERIALS AND TYPES

1. There are only a few combinations of metals that are commonly used for thermocouples. The requirements include: (1) a high coefficient of thermal EMF with temperature, (2) a continuously increasing relationship of EMF to temperature over a long range, (3) freedom from phase changes or other internal phenomena giving rise to discontinuities in the temperature-EMF relation, (4) resistance to oxidation, corrosion or contamination, (5) homogeneity and reproducibility to fit an established temperature-EMF relation. The following paragraphs describe combinations commonly used.

a. The platinum-rhodium thermocouple invented by Le Chatelier is extremely stable and free from internal changes. It is used as the primary device for the reproduction of the International Temperature Scale from the freezing point of antimony (about 630°C) to the freezing point of gold at 1063°C. Its disadvantages are the high cost and the relatively low thermoelectric power.

b. The copper-constantan thermocouple has a well-established temperature-EMF relationship. Its cost is low and it is convenient to use long leads of identical material, which have relatively low resistance. In comparison to iron, copper is resistant to rust at ordinary temperatures.

c. The iron-constantan thermocouple is probably the most widely used, principally because of its low cost and its useful temperature limit is considerably higher than that of copper, up to 1400°F.

d. The Chromel-alumel thermocouple has outstanding resistance to oxidation at high temperatures and is particularly useful in the range from 1400° to 2200°F. It is peculiarly sensitive to contamination by reducing atmospheres, and its cost is relatively high. Extension lead wire of cheaper composition with similar thermoelectric characteristics is available, but its use is not favored for precise work.

e. Chromel-constantan has the highest thermoelectric power of any of the common thermocouples. It can be used up to about 2000°F, and its stability and reproducibility are excellent.

2. The EMF generated by a thermocouple does not depend on the diameter of the wire as does its current handling ability. Therefore, small, fine wire thermocouples are ideally suited for the measurement of temperature in small spaces or when rapid temperature changes require good dynamic characteristics. Time constraints of the magnitude of 1 second are possible in gases at atmospheric pressure moving with a moderate velocity. On many applications, however, an adequate couple life can be achieved only with a heavier wire (for example, 14 gauge) and one or two protecting tubes, both of which cause a reduction in speed of response.

3. At low temperatures (1000°F and below), a single metallic tube is generally adequate. At high temperature, the thermocouple is often inserted in a primary tube of porcelain or fused silica, and this is protected by a secondary tube of metal, silicon carbide, or fire clay. The construction is usually a compromise between service life, dynamic characteristics, and errors due to conduction, radiation, and other losses.

4. Thermocouple circuits have a reference junction (cold junction) from which temperatures are measured. Usually this junction is at 0°C, or 32°F; and in the simplest circuits, the temperature is maintained by an ice and water bath. It is more convenient, with instruments in continuous service, to maintain the reference junction at a temperature slightly above the ambient temperature by a miniature thermostatically controlled oven, and to zero the instrument, allowing for the corresponding voltage. Other instruments allow the reference junction temperature to vary with the ambient conditions within the voltage measuring instrument, and provide a calibrated electrical or mechanical manual adjustment so the instrument reading can be corrected for different ambient temperatures.

5. In recent years, most instruments that are used with only one type of thermocouple have automatic reference-junction compensation, and their scale or chart is calibrated directly in temperature units. In the calibration program, most instruments that use thermocouples are calibrated in electrical units. Figure 1-4 shows some typical circuit connections for thermocouples.

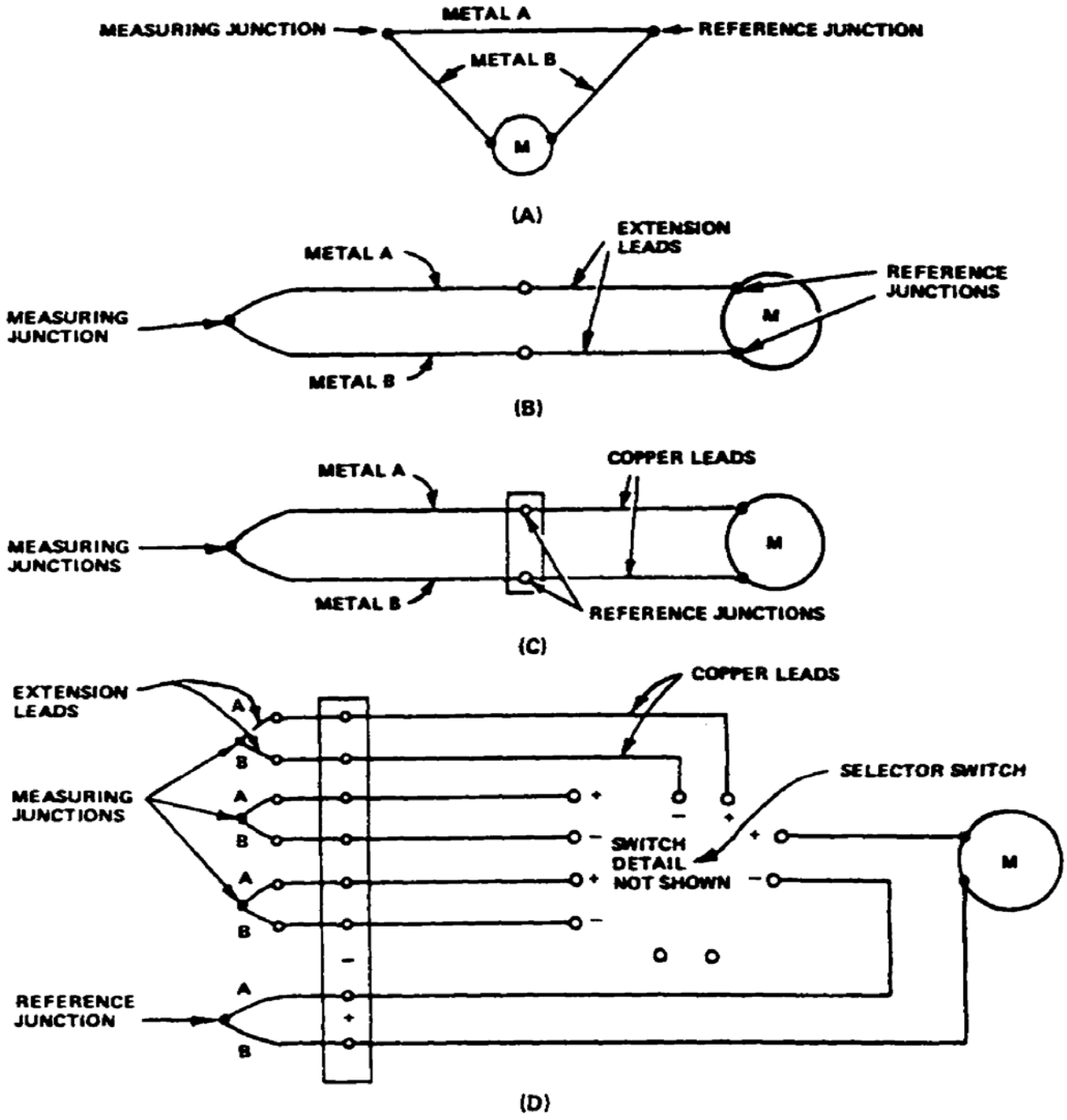


Figure 1-4. Typical thermocouple circuits

6. There are two basic types of thermocouples as far as construction is concerned; direct and indirect. The particular type used depends entirely on the application intended.

a. Direct. A directly heated thermocouple circuit is shown in Figure 1-5. It is called a direct or contact thermocouple because the junctions of the two dissimilar metals are connected directly to the heater. This direct contact with the heater results in a rapid response to any change in heater temperature caused by any current through the heater.

(1) The complete assembly is mounted in an evacuated glass tube to increase the sensitivity by minimizing heat loss to outside atmosphere. In other words, there are no drafts on the thermocouple which would cool the junction and give erroneous readings. The heater wire is a very fine, high resistance wire with negligible frequency effects. The length of the heater is kept short so that it will pass high frequencies without much attenuation. Since the heater is physically small, the heat loss from radiation is also reduced to a minimum.

(2) Although the small size of the heater is beneficial, it imposes a limit on the highest frequency signal that can be measured accurately due to skin effect. Skin effect is the increase in resistance of the heater as the applied frequency is increased. At high frequencies, current tends to flow mostly on the outside surface of a conductor. Skin effect may be reduced if a rod, or hollow wire of the same diameter is used. By this expedient, we make the total skin surface available larger in proportion to the total cross-sectional area of the conductor. Thus the resistance of the conductor is made more constant from DC through the upper frequency limit of the thermocouple.

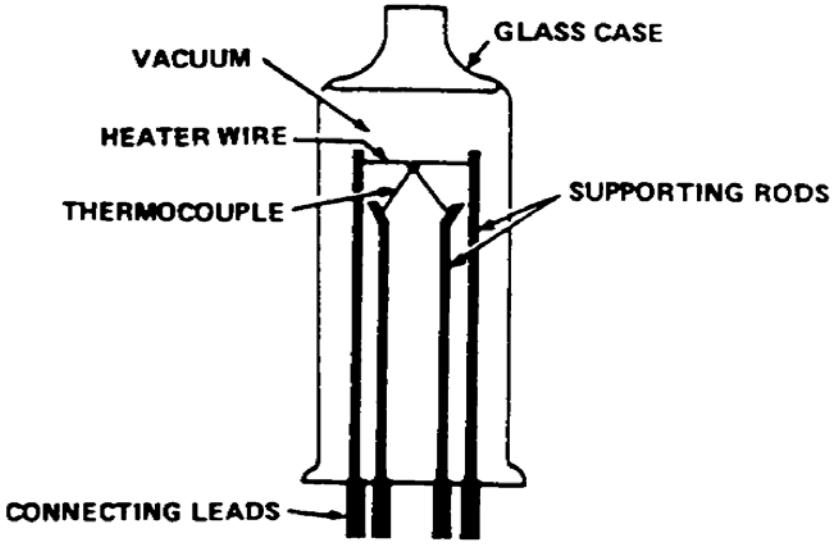


Figure 1-5. Directly heated thermocouple

b. Indirect. As shown in Figure 1-6, there are two different types of indirectly heated thermocouples, isolated and noncontact. These are both similar to the direct type in that they are enclosed in glass tubes. The obvious difference is that the thermocouple and heater do not make electrical contact.

(1) Isolated. This type of thermocouple has the element junction and heater separated by a ceramic or glass insulating bead. This bead maintains the thermal contact but no electrical contact is made. The electrical insulation prevents the signals on the heater from being felt on the thermocouple. The isolation prevents erroneous indications on the monitoring device. This type is recommended for high frequency applications, although it is less sensitive than the contact type. This is because heat must be transferred from the heater, through the bead, and then to the measuring junction, rather than from the heater directly to the junction.

(2) Noncontact. In this type of thermocouple, the element is separated from the heater using air spacing in a draft-free enclosure. The sensitivity of the thermocouple is varied by movement of the junction; the closer to the heater it is placed, the more sensitive to changes in temperature of the heater it becomes. The noncontact type thermocouple is normally used when monitoring current over 150 milliammperes.

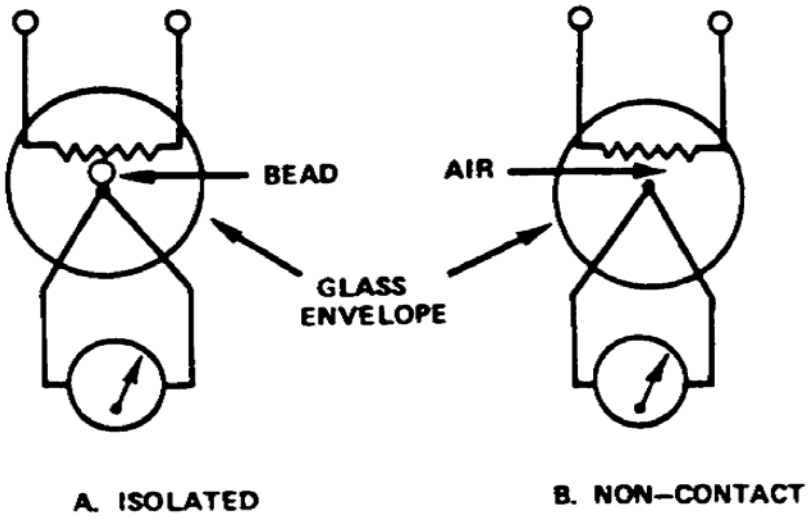


Figure 1-6. Indirectly heated thermocouples

Learning Event 3:
DESCRIBE THERMOCOUPLE APPLICATIONS

1. There are many, many uses made of thermodynamic devices. This subcourse deals with one specific application for thermocouples, their use in electronics. Thermocouples used in electronic instruments are most often referred to as thermal converters. This name is derived from the fact that heat induced in the heater by the current to be measured is converted to DC current in the measuring circuit.

2. As with any volt-ohmmeter (VOM), it is possible to build multirange thermocouple voltmeters, ammeters or wattmeters (figs 1-7 and 1-8). Thermocouples are generally used in some of the better meters exhibiting accuracies of one percent or better. The thermocouple is more accurate than either a standard dynmamometer or rectifier when converting an AC signal to DC. In Figures 1-7 and 1-8, the variable resistor (Rj) is the full scale adjustment. The automatic temperature compensation (ATC) is a resistor with a negative temperature coefficient to compensate for any temperature changes of the reference junction. This temperature compensation is effective over a limited range. The frequency response of multirange thermocouple meters is limited by the frequency response of the input divider circuit rather than that of the thermocouple. For this reason, the multirange meters have a much lower frequency response than single range meters. Another consideration when using a thermocouple in a metering circuit, is that common vacuum thermocouples have a limited current range (2 to 500 mA) and the shunts and multiplier resistors must be chosen with this in mind.

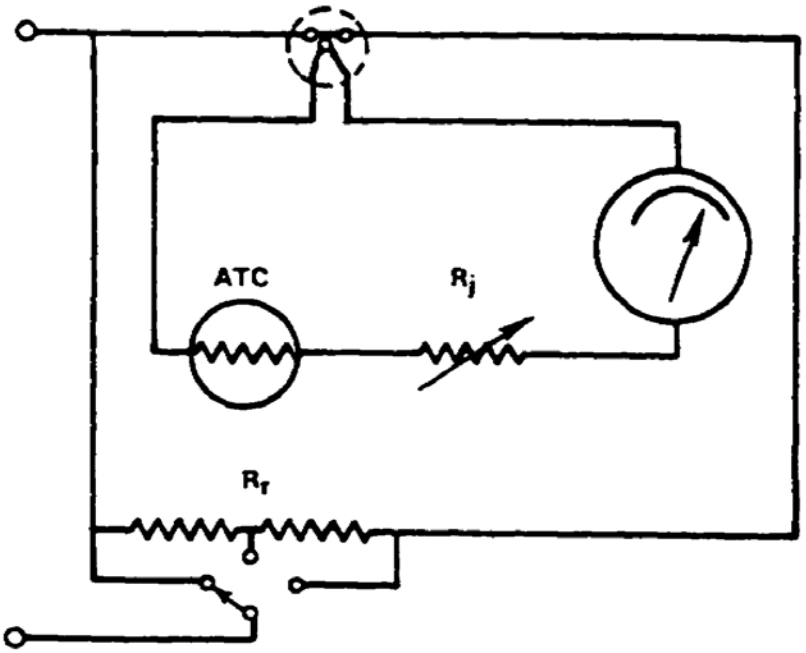


Figure 1-7. Thermocouple ammeter

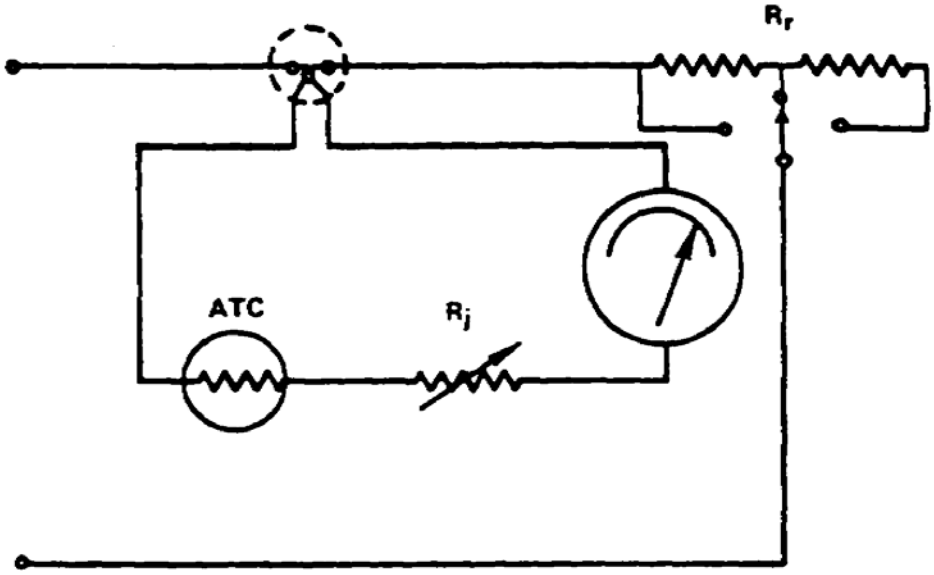


Figure 1-8. Thermocouple voltmeter

3. A number of factors limit the AC to DC transfer accuracy of a thermocouple. One of these factors is the AC-DC reversal error of the thermocouple.

a. In all AC to DC transfer measurements with a thermocouple, the average of the DC response for two directions of current should be taken as the reference upon which the AC measurements are based. The reversed DC average gives a better basis than the response for one direction alone, as effects that lead to small differences in the response for the two directions of direct current are reduced when the average is taken.

b. Reversal differences may be expected in a contact thermal converter because of the flow of the heater current through the hot junction of the thermocouple. This can cause a voltage drop in the thermocouple circuit because of the nonlinearities of the thermal and electrical circuits. This cause of reversal difference is minimized by the special construction techniques used in most high current thermal converters, and is eliminated by the use of a small insulating bead between the heater and the thermocouple in the low current thermal converters.

c. Both Peltier and Thompson effects on a heater can also cause dissymmetry in the temperature rise of the heater and can cause differences in the EMF of the thermocouple unless the hot junction is exactly at the midpoint of the heater.

(1) If the input leads are of a different metal than the heater conductor, Peltier heating and cooling may occur at the junctions of the heater conductor with its input leads. These will be equal and opposite in sign at the two terminals, and, if we can assume complete thermal symmetry, their effect will be to raise the temperature of one terminal by a small amount and to lower the other by an equal amount. Of course, complete thermal symmetry is never attained so Peltier effect may cause a change in the midpoint temperature of the heater.

(2) Thompson heating occurs in solid, single material conductors having a temperature gradient in the direction of the current flow. This will cause a small decrease in the temperature rise at the midpoint of the conductor and can lead to a transfer error in a thermal converter.

(3) With only the normal resistance heating, and with the terminals of the conductor at an equal and fixed temperature, the temperature distribution along the conductor is parabolic. In addition, however, there is Peltier heating or cooling at the junction of dissimilar metals and Thompson heating along each half of the wire. Unlike normal resistance heating, these are dependent on the direction of the current flow and can cause a dissymmetry of the temperature distribution along the conductor which reverses when the direct current through the conductor is reversed.

(4) On alternating current, even at low frequencies, the reversal of current occurs so rapidly that the thermal inertia of the wire prevents any such dissymmetry, and the temperature distribution is unchanged by these thermoelectric effects. This is why AC-DC differences occur. The AC change is fast enough to eliminate the Peltier and Thompson effects while two different polarity DC currents will respond to the Peltier and Thompson effects.

(5) The causes of the AC-DC differences have briefly been explained here and basically they are caused by the following:

(a) Heating of an electrical conductor varies throughout its length.

(b) Heating is not uniform through the heating element.

(c) It is impossible to locate the thermocouple junction in the exact center of the heater.

(d) Heating and cooling takes place at all electrical junctions.

4. Circuit loading is responsible for more errors in the field of calibration than any other source. This is normally caused by placing a low impedance instrument in a measurement setup. The main disadvantage in the use of thermal converter meters is the relatively low impedance. This must always be taken into consideration. First you must determine if the circuit under test can tolerate the low impedance. Then you must determine whether or not that circuit will be altered by the low input impedance. Input impedances for some of the better instruments of this type range from 100-200 ohms per volt. You can see that such low input impedance will limit their use.

a. In addition to the low input impedance, a second disadvantage is skin effect. As the frequency increases, the thermal converter heater tends to increase in resistance. This causes the heater temperature produced by a given current to be greater than at lower frequencies which results in a higher output from the thermocouple element and consequently an erroneous reading. Essentially what happens is, the current applied to a given conductor will, at higher frequencies, tend to flow closer to the surface of the conductor. The resulting effect is that the resistance tends to increase, giving off more heat for a given current and causing considerably more radiation heat loss.

b. The primary methods of compensating for skin effect involves the physical construction of the thermocouple element and its heater circuit. Where frequency range is critical the method of thermal conversion used is selected for the increased sensitivity of measurement at the high frequencies. Additionally, the physical size of the heater element and its leads becomes critical as frequency is increased. Therefore, the size, length and type of heater wire are varied to minimize the loss of frequency response due to skin effect.

c. For thermal converters which are used to measure small quantities of current, smaller heater wires can be used. Because the frequency at which skin effect first becomes appreciable is higher for smaller wires, low current thermocouples are generally unaffected up to approximately 30 megacycles. Most thermal converter meters are designed to measure large currents and the high frequency response is considerably less. Since the wire size is necessarily large to handle the larger current, the type of heater wire rather that the size is the factor involved in frequency compensation. Ribbon heaters are normally associated with large currents, however, they have relatively large skin effects. For this reason solid wire or thin-walled tubing is used in the heater element because their electrical behavior is instrumental in reducing skin effect.

d. At extremely high frequencies where length is an appreciable fraction of a wavelength, the current developed along the heater will not be uniform. The indication given for the signal being measured becomes inaccurate. For this reason the heater and its leads must be kept extremely short in respect to a wavelength if high accuracy is to be expected in the measurement.

e. Thermocouples can be easily destroyed. There is no visible warning that a thermocouple is overloaded. In fact, a thermocouple meter may not ever reach full scale before the heater is burned out. When using this equipment, never exceed the maximum voltage on a given range, even for an instant. Thermocouples that you will encounter are rated at predetermined resistances. Excessive current will cause a solder effect to occur in which the junction rapidly deteriorates and often melts. Always connect thermocouple instruments into the circuit last and ensure that the attenuator is set to its highest range. Always down range and increase the input slowly, allowing time for the instrument to react. Many thermocouples are matched to the circuit in which they are installed at the factory. One simple mistake can result in a large expenditure and an extended down time.

LESSON 1
PRACTICE EXERCISE

1. What is the output of a thermocouple?

   a. RMS
   b. Peak
   c. Average
   d. DC

2. Select the incorrect statement.

   a. The heat difference between the reference junctions is determined by the average value of the input.
   b. The current available from a thermocouple is small
   c. A thermocouple develops EMF when there is a temperature difference between the two junctions
   d. The measuring junction is also referred to as the hot junction

3. Which thermocouple phenomenon involves the rejection of heat at the measuring junction?

   a. Law of Intermediate Metals
   b. Seebeck Effect
   c. Thompson Effect
   d. Peltier Effect

4. What heating effect occurs in solid, single material conductors having a temperature gradient in the direction of the current flow?

   a. Thompson heating
   b. Peltier heating
   c. Conductor heating
   d. Reversal heating

5. Which is not a requirement for thermocouple metal composition?

   a. An increasing relation of EMF to temperature
   b. Resistance to corrosion
   c. A low coefficient of thermal EMF to temperature
   d. Freedom from phenomena resulting in discontinuities in the temperature-EMF relation

6. Which thermocouple is the most widely used?

   a. Platinum-rhodium
   b. Copper-constantan
   c. Iron-constantan
   d. Chromel-alumel

7. The size, length and type of heater wire used in thermocouples are varied to minimize loss of frequency response due to _____.

   a. Power dissipated
   b. Skin effect
   c. Changes in EMF
   d. Air spacing

8. Skin effect may be reduced by:

   a. Reducing the heater surface area
   b. Decreasing the wire gauge
   c. Increasing the applied signal frequency
   d. Increasing the heater surface area

9. Which type thermocouple has the element junction and heater separated by a bead?

   a. Direct
   b. Isolated
   c. Contact
   d. Noncontact

LESSON 2
DCLF THERMAL TRANSFER STANDARDS

TASK

Describe the function and operation of each thermal transfer standard.

CONDITIONS

Given the information and illustrations about theory and applications relating to thermal transfer standards.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to at least 80 percent of the multiple-choice test covering theory and application of thermal transfer standards.

REFERENCES

None

Learning Event 1:
DESCRIBE MODEL 540B THERMAL TRANSFER STANDARD

1. As illustrated by Figure 2-1, there are only three instruments involved in a basic AC-DC thermal transfer measurement; a thermal transfer standard, a DC voltage standard, and the AC source that is to be calibrated. The thermal transfer standard is the center of the measurement. It contains three basic items; a thermocouple, a galvanometer, and an internal DC reference supply.

a. To perform the measurement, you apply the AC source voltage to the input of the thermal transfer standard. This AC voltage is attenuated by the range switch prior to being felt on the thermocouple heater. The resulting DC output from the thermocouple is applied to one side of the galvanometer. The internal DC reference voltage is present on the other side of the galvanometer and it is manually adjusted to balance against the thermocouple DC voltage, causing the galvanometer to indicate a null or zero.

b. The next step is to remove the AC input and connect the DC voltage standard output to the thermal transfer standard. The reference controls on the thermal transfer standard are not touched. The DC voltage output is now adjusted until the galvanometer reads zero. You can now read the RMS value of the AC voltage directly from the DC voltage standard. This is made possible because the heating effect of an RMS value of the AC voltage applied to a thermocouple is the same as an equivalent value of DC voltage applied to the same thermocouple.

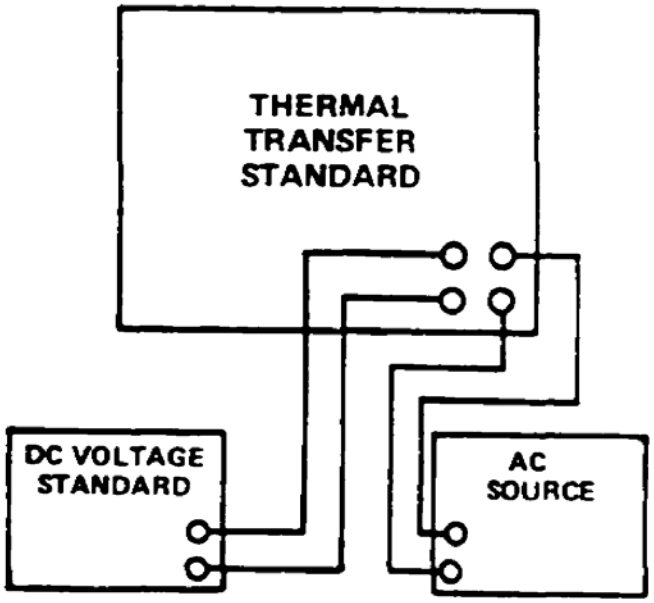


Figure 2-1. AC voltage calibration using AC-DC transfer technique

2. Dependent on the type measurement required at the secondary transfer level by the AREA TMDE SUPPORT TEAM (ATST), you may use one or all of the following instruments which are addressed in this lesson: the Model 540B Thermal Transfer Standard, Model 1395 Coaxial Thermal Converter Set, and the Model B7842 Thermal Converter Set.

3. The Model 540B, together with the Model A54-2 Voltage Plug-in Unit (both of which are pictured in Figure 2-2), constitute an AC-DC Thermal Transfer Standard. As previously mentioned, these instruments are used for measuring unknown AC voltages and calibrating AC voltage sources. The unit has 14 ranges of input from 0.5 volts to 1,000 volts. It is furnished with a solid-state galvanometer, internal DC reference, search meter, and battery power supply. A voltage protection circuit protects all internal circuits from damage as a result of over-voltages of up to 1,500 volts on any range.

a. The instrument features an input impedance of 182 ohms/volt in all voltage modes. The galvanometer does not require special mechanical orientation for proper operation and is no more fragile than any normal meter movement. The circuit is equipped with an internal calibration circuit that provides easy and rapid calibration of meter deflection sensitivity representing 0.1 percent and 0.01 percent at any input. The accuracy depends on the range in use and the frequency of the AC voltage being measured and varies from 0.2 percent to 0.01 percent. The thermocouple reversal error (explained in Lesson 1) is less than 0.01 percent of input at 100 percent of rated current or voltage and less than 0.3 percent at 50 percent of rated current or voltage.

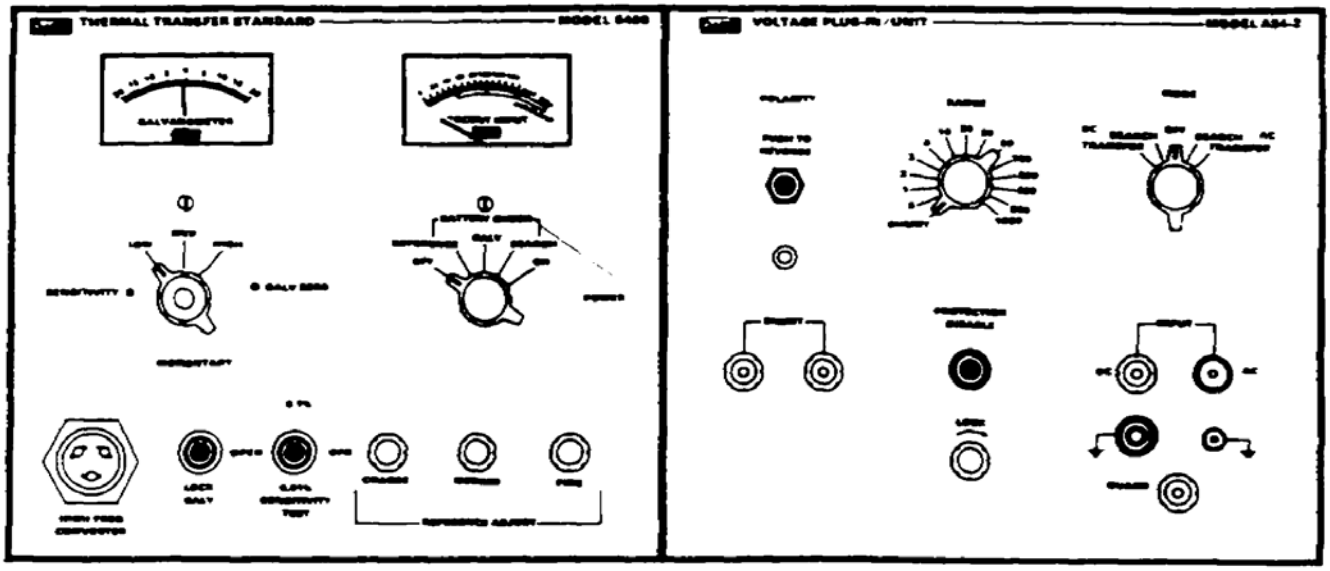


Figure 2-2. Model 540B Thermal Transfer Standard and Model A54-2 Voltage Plug-in Unit

b. The instrument utilizes a search circuit that gives a visual indication of the input voltage as a percentage of the voltage range selected. If the instrument was set up for the 1000-volt range and there was a 500-volt input, the visual indication would be 50 percent; if there was a 250-volt input, the percent input meter would read 25 percent.

c. Refer to Figure 2-3 throughout the following explanation of the Model 540B front panel. The POWER switch provides battery power to the instrument when all the way clockwise to ON. When in the BATTERY CHECK, REFERENCE, GALV, or SEARCH positions the meter immediately above the POWER switch will indicate the condition of each set of batteries.

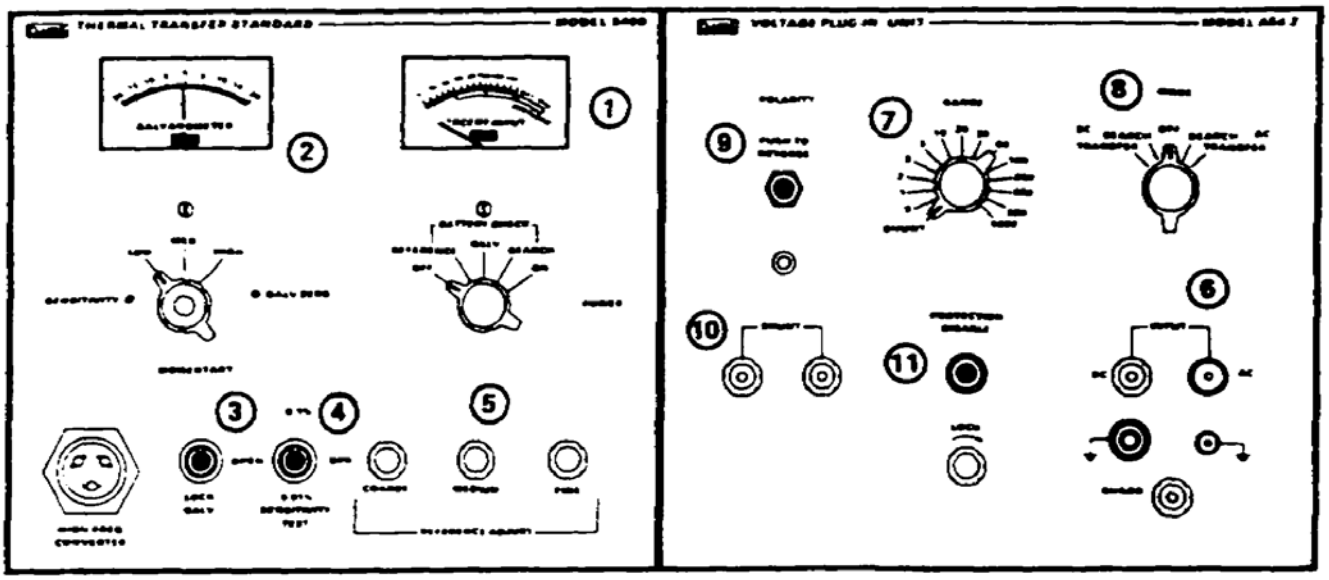


Figure 2-3. Model 540B and Model A54-2 controls, terminals, and indicators

(1) The PERCENT INPUT meter indicates the battery condition. The pointer should fall within the BAT OK region of the meter scale. It is also the search indicator which indicates the percentage of input of the range selected. If the input is from 50 to 100 percent of the range selected, the pointer will be in a green band; if the input is 100 to 150 percent of input, the pointer will be in the red area of the meter scale.

(2) The galvanometer is the null indicating device which is used to determine the balance between the variable difference voltage and the DC output from the thermocouple. The SENSITIVITY switch selects the sensitivity of the galvanometer; LOW, MED, or HIGH. In the center of the SENSITIVITY switch is the GALV ZERO, this is the electrical zero control for the galvanometer. Initial setting of the sensitivity switch should be on LOW.

(3) The GALV switch electrically connects the galvanometer circuit between the thermocouple output and the variable internal reference supply when in the LOCK or MOMENTARY positions. The GALV switch is briefly pushed from OPEN to MOMENTARY to determine if the galvanometer will indicate on scale. After an on scale indication is obtained, the GALV switch may be set to LOCK.

(4) The SENSITIVITY TEST switch is used to determine the amount of deflection of the galvanometer for 0.1 percent and 0.01 percent changes in input.

(5) The three REFERENCE adjust controls; COARSE, MEDIUM, and FINE, vary the reference voltage for galvanometer balance.

(6) There are two pair of input connectors, DC and AC. The DC binding posts are provided for connecting DC voltage to the Model 540B. The positive lead must be connected to the upper post and the negative lead to the lower post (chassis ground). AC voltages may be applied to the AC connector, either through a UHF-type connector or a standard dual banana plug.

(7) The RANGE switch selects the proper dropping resistor and compensating network for measurements of voltage up to and including the voltage indicated; this may be AC or DC.

(8) The MODE switch selects SEARCH or TRANSFER modes for either AC or DC input to the instrument. Range selection is made in the SEARCH modes by selecting a voltage range that gives a PERCENT INPUT meter indication between 50 and 100 percent.

(9) The POLARITY is a push button switch used to reverse the input to the thermocouple. This facilitates measurement of the reversal error to the thermocouple.

(10) The SHUNT terminals are provided to accept current shunts when the RANGE switch is set to the SHUNT position.

(11) The PROTECTION DISABLE push button, when depressed, disconnects the diode protection circuit which is parallel with the thermocouple.

d. High order accuracy can be obtained with this instrument only if the user is aware of certain limitations and takes appropriate precautions as follows:

(1) Bead type thermocouples, like that used in the Model 540B, exhibit a small exponentially decreasing drift of EMF after a steady heater current is initially applied. Allow approximately 10 minutes for the thermocouple element to stabilize. After the stabilization time, the drift should be less than two small divisions per minute in the HIGH sensitivity position. When changing to different levels of input after the stabilization period, a wait of only a few minutes is necessary before continuing with measurements. Any observed drift should be evaluated quantitatively.

(2) Connection errors should be evaluated and minimized when the transfer standard is used to calibrate other instruments. These errors can often be detected by changing the length and position of the leads. Short coaxial leads should be used when possible. These errors can be significant at high test frequencies.

(3) Radio frequency interference can be particularly troublesome with low-current thermoelements. The thermocouple in the Model 540B is encased in a steel shield to minimize stray field pick-up. However, to ensure accuracy, the Model 540B should be used in areas of relatively low field strength.

(4) The number of transfers will vary with the degree of accuracy required. In general, it is suggested that three separate transfers (DC to AC and back to DC constitutes one transfer) be made for any single measurement. This will be adequate only if a good degree of repeatability is achieved. Difficulty in repeating any measurement can be caused by any number of problems, the most common of which are poor connections, unstable sources, and interference from stray capacitance or energy fields. Any factor which detracts from repeatability must be eliminated before accurate transfers can be made.

(5) All of the components and elements in the Model 540B have been selected to minimize environmental sensitivity. It is suggested that the Model 540B be given time enough to arrive at the environmental temperature before it is used. If the Model 540B is used before it has arrived at the temperature of the environment where it is to be used, excessive thermal drift will be observed, making accurate transfers more difficult.

(6) The Model 540B imposes two load conditions on the AC source. The AC source sees the 182 ohms/volt input impedance of the Model 540B when the MODE switch is in the AC TRANSFER position. When the MODE switch is in the OFF or DC TRANSFER positions, the AC source sees the Model 540B as an open circuit. This impedance change across the AC source causes a corresponding output level change from the AC source. When calibrating a device that is quite sensitive to level changes, the user should determine if the AC source level changes could adversely affect the device. The user should take appropriate precautions, such as switching the device out of the calibration circuit before turning the MODE switch to the OFF or DC positions, should such a situation arise.

(7) Though the internal range selection components and thermocouple in the Model 540B are protected from overloads in the voltage mode; no protection is provided in the current mode or for external shunts or high frequency converters. These devices are easily damaged or destroyed by overloads and all possible precautions should be observed. External switching transients cause many such overloads and should be avoided. It is possible to damage a thermal converter without completely destroying it. One of the characteristics which change, and indicate a damaged thermal element, is DC reversal error. Should the reversal error of any thermal element change after a suspected overload, it is reasonable to assume that damage has occurred and the device should be recalibrated.

(8) During all transfer measurements the operator must remain alert to changes in readings regardless of their cause. All such changes should be analyzed and corrective measures taken in order to ensure the accuracy of the transfer measurements.

e. Prior to operating the Model 540B, you should always check the battery charge. When the POWER switch is positioned at either REFERENCE, GALV, or SEARCH, the PERCENT INPUT meter must indicate above the lower limit of the BAT band on the meter scale in all BAT CHECK positions.

f. It is recommended that a DC reversal error check be made and recorded for future reference, in the event that suspected overload damage has occurred to the thermocouple. This value can be used for comparison, as discussed in step (g) of para 9. The amount of DC reversal error at a particular input level may be measured as follows:

(1) Apply the desired DC voltage or current to the A54 DC INPUT terminals. Determine the deflection sensitivity in the HIGH SENSITIVITY position.

(2) Adjust the REFERENCE ADJUST control until a GALVANOMETER indication of zero is obtained in the HIGH SENSITIVITY position.

(3) Set the GALV switch to OPEN. Depress the POLARITY switch until it locks and remains in the depressed position. Wait approximately 5 seconds; then place the GALV switch in the LOCK position.

(4) The resulting GALVANOMETER deflection indicates the amount of DC reversal error. The percent change may be computed by multiplying the deflection sensitivity determined in step (a) by the amount of DC reversal error.

(5) Set the GALV switch to OPEN. Set the POLARITY switch to its normal (up) position.

g. Throughout the following AC voltage measurement procedure, refer back to Figure 2-3 as necessary to ensure your understanding of the operating procedure. Before connecting and energizing the Model 540B, always set the RANGE switch to 1000, MODE switch to OFF, and make sure the GALV switch is in the OPEN position. Perform the battery check as described in para 10.

(1) Set the SENSITIVITY switch to MEDIUM, POWER switch to ON and adjust the GALV zero control for zero on the galvanometer after sufficient warmup time.

(2) Connect the unknown AC voltage to the AC INPUT terminal(s). Set the MODE switch to AC SEARCH and down range the RANGE switch slowly until the PERCENT INPUT meter has an indication in the green area. For example, with the RANGE switch set to 10 and a PERCENT INPUT meter indication of 80 percent the input voltage must be approximately 8 volts.

(3) Set the MODE switch to AC TRANSFER. The galvanometer can now be nulled as follows: set the SENSITIVITY switch on LOW and tap the GALV switch to MOMENTARY. Observe the deflection on the galvanometer; if it deflects left, turn the REFERENCE ADJUST COARSE control clockwise until the galvanometer reads zero, if the galvanometer deflects right, adjust the COARSE control counterclockwise until the galvanometer reads zero.

(4) Once the galvanometer reads zero in the LOW SENSITIVITY position, go to the MEDIUM SENSITIVITY position and again use the GALV switch and the MEDIUM and FINE REFERENCE ADJUST controls for zero on the galvanometer.

(5) After you zero the galvanometer in the MEDIUM position, go to the HIGH position and again, tapping the GALV switch, adjust the FINE REFERENCE ADJUST control until the galvanometer indicates zero. After this final zero, do not touch the REFERENCE ADJUST controls again.

(6) Disconnect the AC input and connect a DC voltage standard to the DC INPUT terminals. From the foregoing procedure, you know that the unknown is about 8 VAC, 80 percent of the 10 range, so you can set the DC voltage standard for about 8 VDC output. Set the MODE switch to DC SEARCH and the PERCENT INPUT meter should indicate about 80 percent.

(7) Set the MODE switch to DC TRANSFER and the SENSITIVITY switch to LOW. Null the galvanometer using the output controls on the DC voltage standard. Turn the SENSITIVITY switch to MEDIUM and then to HIGH, nulling the galvanometer as you go. The value of the unknown AC voltage can be read out on the DC voltage standard.

h. The theory of operation is explained in this lesson to assist in understanding the operation and trouble-correcting analysis of the Model 540B. The figures presented in this section are simplified for easier understanding. The block diagram will be explained first, followed by a detailed description of each functional section of the instrument. Refer to Figure 2-4 throughout the following explanation.

(1) With the MODE switch in the AC SEARCH position, the input signal passes from the binding posts through the MODE switch, through the first protection relay (K801) and to the search compensation attenuator. The output of the attenuator is connected to another section of the MODE switch and to the protection amplifier. The signal path is through the MODE switch to the search amplifier where the AC signal is amplified and then rectified and filtered. R704 is connected across the input in SEARCH to provide proper input impedance. The output of the search amplifier is then connected through the MODE switch to the PERCENT INPUT meter where the needle deflection is calibrated to read in percentage of input per range selected.

(2) When the MODE switch is in the DC SEARCH position the direct current path is identical with the AC path except no amplification is required and the MODE switch provides an alternate path around the search amplifier. Calibration adjustments are provided for the search ranges in the search amplifier and in the alternate DC path around the search amplifier.

(3) With the MODE switch in the AC or DC TRANSFER positions, the signal from the input terminals passes through the MODE switch, then through the first protection relay (K801), and feeds both compensated attenuators. The search-compensated attenuator output is connected to the protection amplifier and the search amplifier. The transfer compensated attenuator feeds through the MODE switch, then through the second projection relay (K701). From the second protection relay, the signal feeds the thermocouple. The output of the thermocouple is fed to the galvanometer in such a manner that it is opposed or balanced by the output from the reference supply. The galvanometer indicates the null or balance between the two.

(4) The protection amplifier is always connected to the output of the search attenuator, and is designed to function on a pre-set level of AC or DC. When the protection amplifier operates it causes relays K701 and K801 to disconnect the input from the attenuators and open the circuit to the thermocouple. The protection amplifier also causes relay K301 to close a circuit from the battery supply which causes the PERCENT INPUT meter needle to deflect into the OVERLOAD area of the meter scale. Once the protection amplifier has operated, it must be reset manually by turning the MODE switch to OFF. The cause of the overload should be located and removed and the range increased or other remedial action taken before returning the MODE switch to it's operating position.

(5) When the Model 540B is operated in the SHUNT mode, no protection is provided for either the Model 540B thermocouple or for the current shunt. It is necessary to exercise caution when operating in this mode to prevent damage to the instrument.

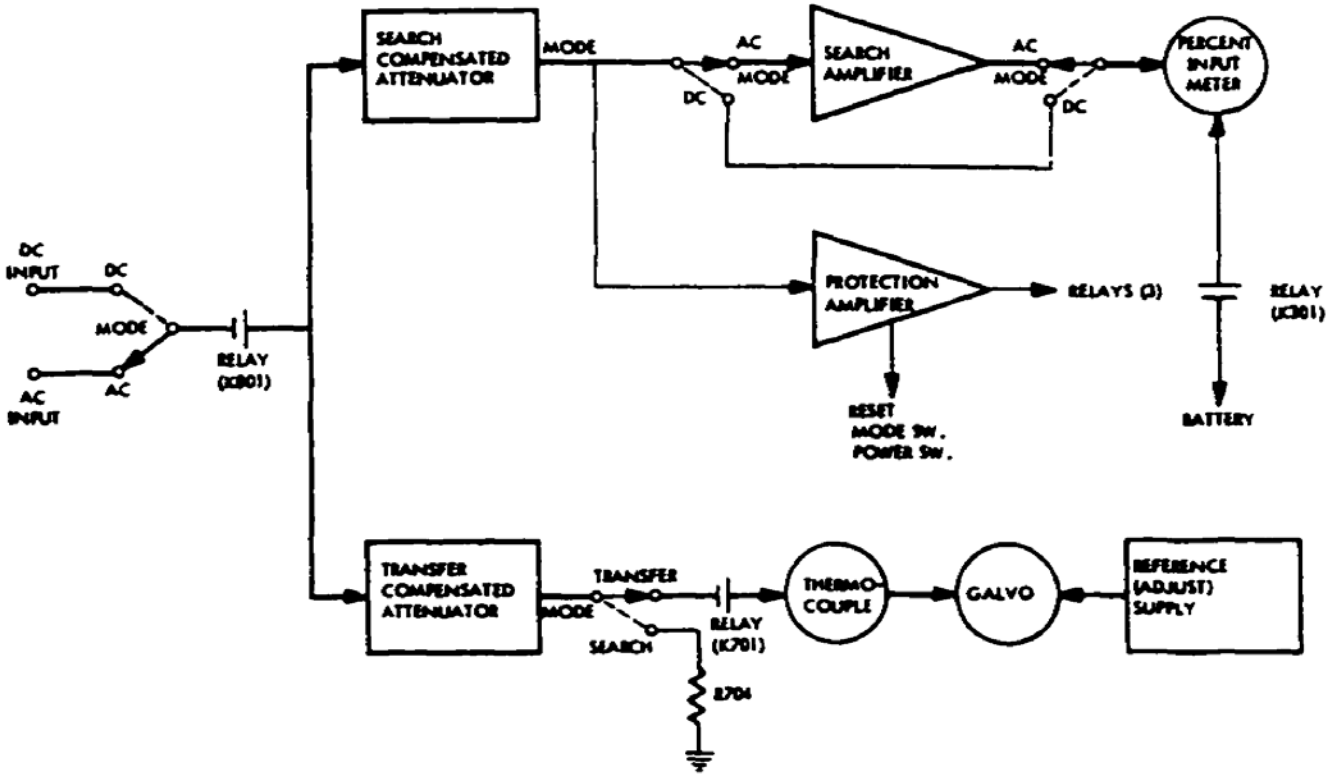


Figure 2-4. Model 540B block diagram

i. Figure 2-5 is a simplified representation of the search circuit. Attenuator components shown are those selected when the range switch is in the I-V position. The search circuit is composed of three basic elements; the search-compensated attenuator, search amplifier, and percent input meter.

(1) The search-compensated attenuator is compensated to equalize the output of the search amplifier in order to give the percent input reading a favorable deflection/frequency response.

(2) The search amplifier is a two-stage transistor amplifier composed of Q301 and Q302 and the associated parts. Low frequency adjustment and calibration is accomplished with R310. High frequencies are calibrated with C305. CR301 and CR302 rectify the amplified AC and capacitors C303 and C304 filter the resultant DC voltage for application to the PERCENT INPUT meter. The search amplifier is not used in DC SEARCH and a path is provided by the MODE switch to apply DC directly to the meter from the attenuator.

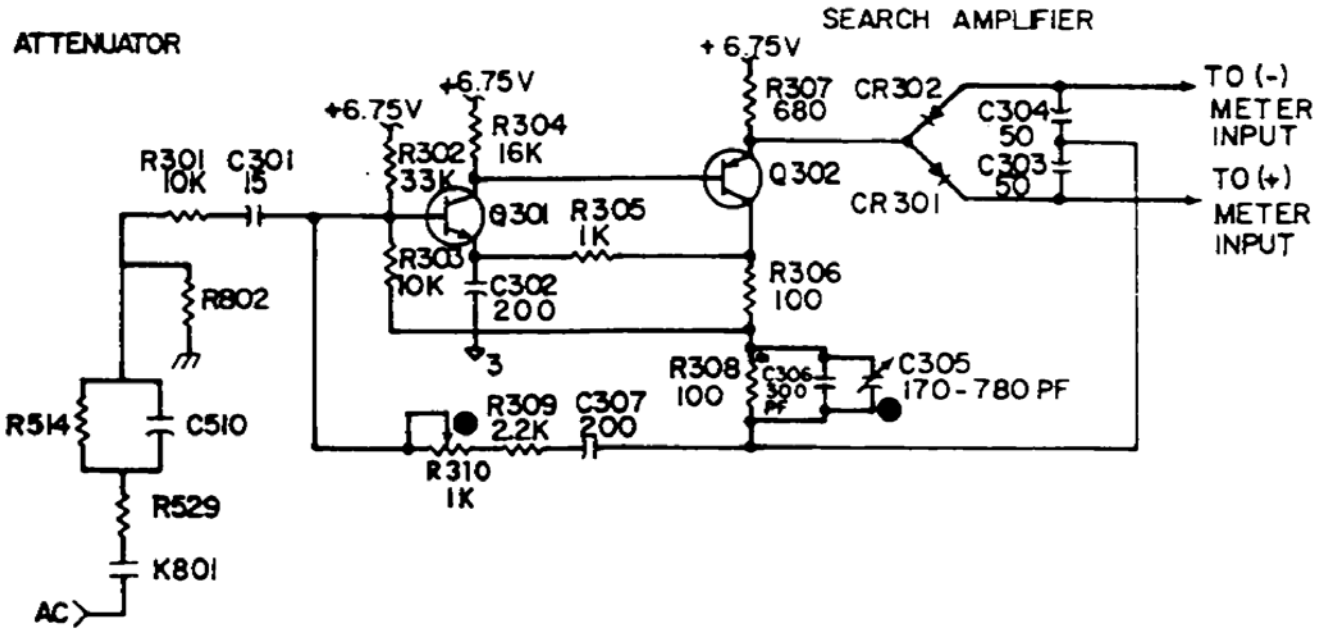


Figure 2-5. Search circuit

j. The protection circuit is composed of an amplifier and two relays which interrupt current flow to the attenuators and the thermocouple, plus a set of diodes which provide additional protective features. It is characteristic of thermocouples to be able to withstand overloads of rather large magnitude for short periods of time. Diodes CR701 through CR704 (fig 2-6) appear across the input of the A54 portion of the 540B and are biased in such a manner as not to conduct under normal operation. In the event of an overload, these diodes conduct and provide an alternate circuit, shunting the input to the thermocouple until the protection amplifier can operate the protection relays.

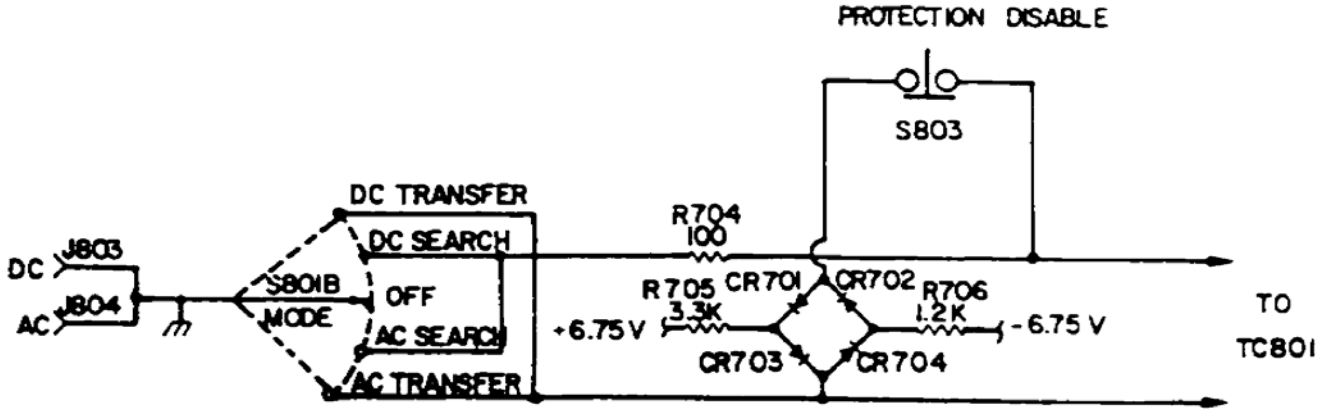


Figure 2-6. Protection disable circuit

(1) The protection amplifier (fig 2-7) is a single operation device designed to remain in a stable state until a voltage is applied to it that is in excess of the operating point. Once overloaded, the amplifier operates the protection relays and holds them operated until power is removed from the protection amplifier. The three transistors in the protection amplifier are Q303, Q304, and Q305. Under normal (non-overloaded) conditions there is sufficient current flow through Q305 to hold relays K701 and K801 in their operated positions. Transistors Q303 and Q304 are cut off, and remain so until the voltage across R313 raises to such a value as to start conduction. Once conduction is started, each transistor assists the other into faster saturation which lowers the voltage at the emitter of Q303. This emitter is connected to the base of Q305 and this voltage being lowered causes Q305 to cut off, releasing the protection relays by stopping the current flow to them. R314 is used to calibrate the operating point of the protection amplifier. The diode bridge composed of CR310 through CR313 is used to protect the transistors of the protection amplifier from overloads and voltage surges which might damage them.

(2) Two diodes have been included in the protection circuit to "speed up" the operation of the protection amplifier when moderate overloads occur. CR307 and CR314 present a low resistance path around R311 whenever the voltage drop across that register exceeds the conduction voltage of the diodes. Without these diodes, the time constant of R311 and C309 is sufficiently long to slow the operation of the protection amplifier enough to damage the thermocouple or other components under conditions of moderate overload, if the "speed up" diodes were not provided.

(3) Resetting the protection amplifier is accomplished by cutting off the voltage to it. It is always advisable to determine the cause of the overload before attempting to reset the circuit. The voltage may be cut off to the protection amplifier by two methods. The MODE switch may be placed in the OFF position or the POWER switch may be operated to any position other than ON. Either of these actions will cause an interruption in the battery power to the protection amplifier. The preferred method is resetting the protection circuit with the MODE switch.

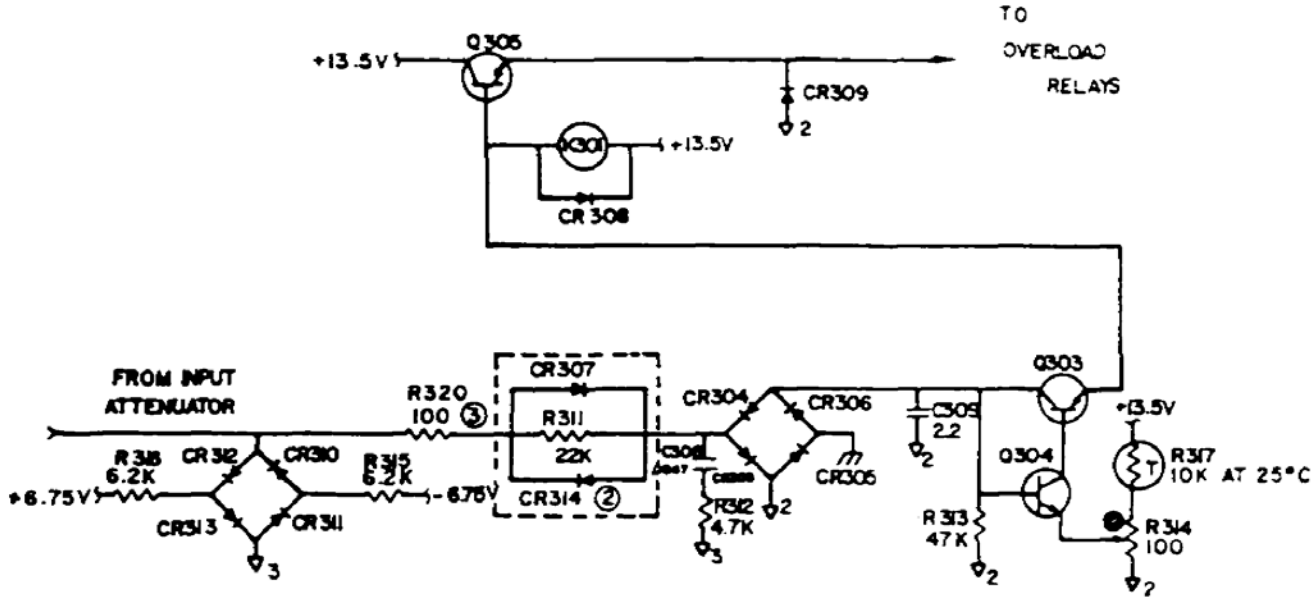


Figure 2-7. Protection amplifier

k. The thermocouple element has been tested and selected at the factory and placed in an insulating case with a standard octal plug base. The thermocouple element is the high vacuum, insulated type with a nominal output of 7 millivolts at rated input. The Model A54 unit will have to be rechecked for calibration accuracy if the thermocouple is replaced. The input to the thermocouple may be reversed by operating the POLARITY switch located on the front panel of the Model A54 plug-in unit. With this switch it is possible to check the turn-over error of the thermocouple with a minimum of effort.

l. When using the transfer standard it is not necessary to measure the output voltage of the thermocouple, it is necessary only to provide a means of detecting and comparing the thermocouple output accurately when making transfer measurements. A variable voltage source has been designed into the Model 540B which fulfills the stability and resolution requirements for this application. Referring to Figure 2-8, the adjustment of the REFERENCE ADJUST controls COARSE, MEDIUM and FINE will vary the voltage at point b, from zero to approximately 14 millivolts. The MOMENTARY position on the GALV switch makes it possible to search out and find an approximate null on the galvanometer with the COARSE control without applying a steady overload to the galvanometer. The LOCK position allows a fixed path for use while adjusting the MEDIUM and FINE controls to maintain the galvanometer balance in successively more sensitive ranges.

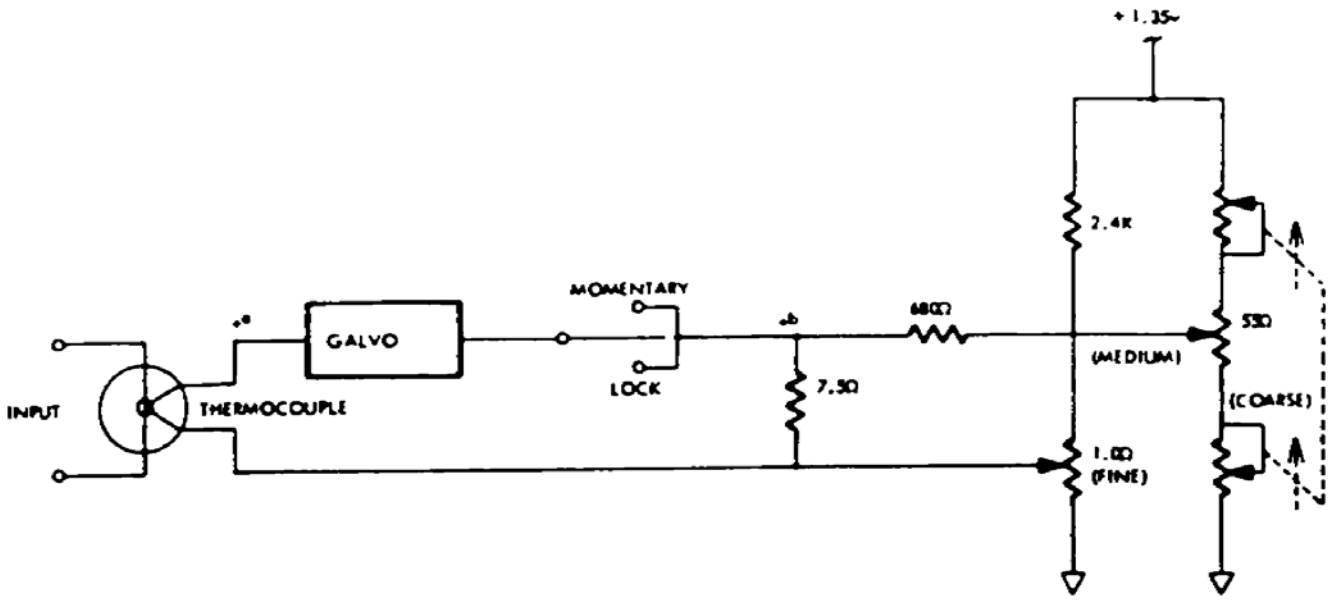


Figure 2-8. Simplified balance network

m. When a DC voltage from the thermocouple and the reference supply is applied to the galvanometer circuit (fig 2-9), the magnetic modulator (T2) produces a 5 kHz output containing magnitude and polarity information relative to the input DC. This 5 kHz signal is then applied to a tuned carrier amplifier where the signal is amplified and undesirable frequencies are attenuated. The tuned carrier amplifier output is then fed to the synchronous demodulator. The demodulator is a balanced demodulator that has no output when no signal is applied. The push-pull oscillator and frequency doubler generates a 2.5 kHz signal that is fed to the magnetic modulator and a 5 kHz signal that is fed to the synchronous demodulator. With DC applied to the input of the magnetic modulator, a DC current flows through the meter which is proportional in magnitude and like in polarity to the input DC.

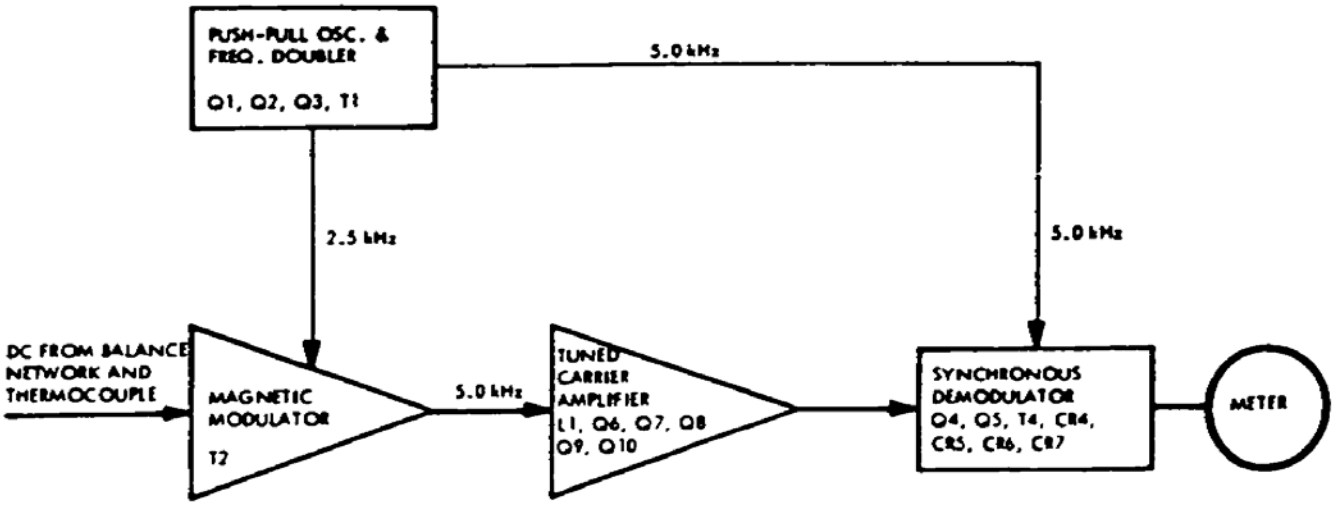


Figure 2-9. Galvanometer block diagram

n. Push-pull oscillator and frequency doubler in the nulling circuit (fig 2-10) consists of Transistors Q1 and Q2 which oscillate at a frequency of 2.5 kHz as determined by C2 and T1. Transformer T1 is adjustable and is used to set the operation frequency of the instrument. Transistor Q3 is used to control the amplitude of the oscillator output. The output of the oscillator, appearing across R10, peaks at 5 kHz rate and is used to drive the synchronous demodulator. The 2.5 kHz signal from the oscillator is fed to the magnetic modulator from windings on transformer T1.

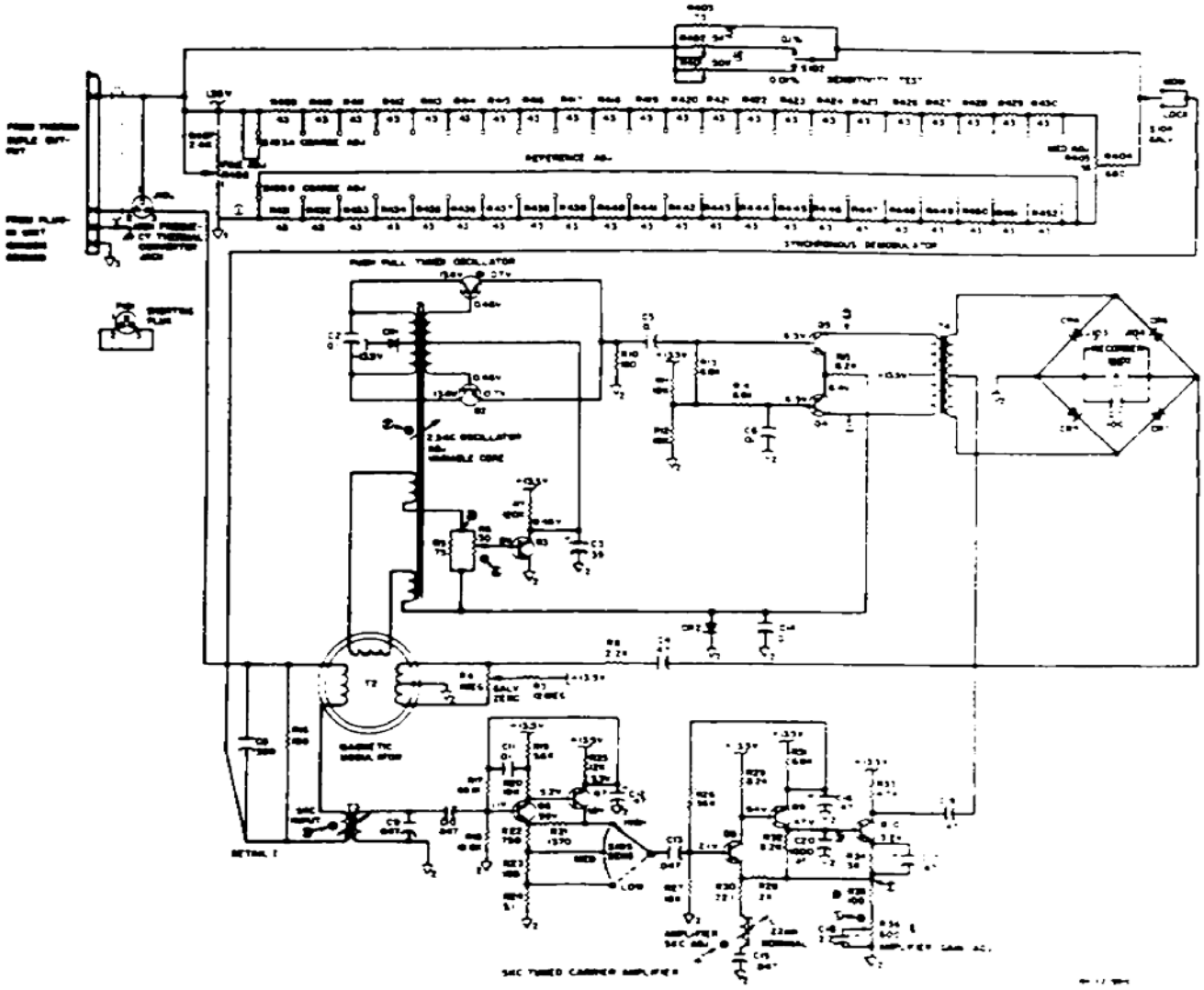


Figure 2-10. Nulling circuit

(1) The magnetic modulator has been designed in such a manner as to produce a 5 kHz output. This 5 kHz output is proportional in level to the DC input of the magnetic modulator and its phase is dependent on the direction of the input current. R4 is the front panel zero adjust used to balance the modulator. The 5 kHz signal from the magnetic modulator is fed to transformer T3 which is the input for the tuned carrier amplifier.

(2) The input transformer to the tuned carrier amplifier is tuned to resonance at 5 kHz during calibration. The signal is then fed to a two-stage transistor amplifier. The SENSITIVITY switch controls the gain of these stages (Q6 and Q7). A variable inductance and series capacitor in the emitter circuit of Q8 serve to exclude all frequencies from the remaining stages except the desired 5 kHz. The variable inductance L1 is tuned for maximum output during calibration of the instrument. R36 is provided to adjust the gain of the tuned carrier amplifier and is set during calibration of the instrument to provide 5 kHz level to the synchronous demodulator.

(3) The primary components of the synchronous demodulator are transformer T4, transistors Q4 and Q5, and diodes CR4 through CR7. The 5.0 kHz synchronizing signal to the demodulator is fed from the push-pull oscillator and frequency doubler through C5. The 5.0 kHz signal to be demodulated is fed through C19 from the tuned carrier amplifier. Increasing the level of the signal from the tuned carrier amplifier results in higher synchronous demodulator output appearing across the diode bridge and meter. It is characteristic of the synchronous demodulator that phase reversals in signal input, with no change in the synchronizing signal, cause reversals in the output of the demodulator.

o. Battery check circuits (fig 2-11) have been provided to enable the operator to determine the adequacy of each of the battery supplies. Placing the POWER switch in the REFERENCE BATTERY CHECK position connects the PERCENT INPUT meter in series with the reference battery and resistors R457 and R462. Resistor R458 has been provided to load the battery so that the battery check is accomplished under load. R462 has been calibrated so that the lower limit of the battery check band on the PERCENT INPUT meter coincides with 1.0 volts from the reference battery BT105.

(1) With the POWER switch in the GALV BATTERY CHECK position, the PERCENT INPUT meter is connected in series with the galvanometer battery supply and resistors R461 and R455. Resistor R461 is adjusted so that the meter will indicate at the lower extreme of the battery check band when 11.5 volts is supplied across the load resistor R456. Since the measurement is made under load, it assures that adequate battery voltage is available for the galvanometer and relay circuits.

(2) With the POWER switch in the SEARCH BATTERY CHECK position, the PERCENT INPUT meter is connected in series with the search battery supply and resistors R453 and R460. Resistor R460 is adjusted so that the meter will indicate at the lower extreme of the battery check band when 11.5 volts is supplied across the load resistor R454.

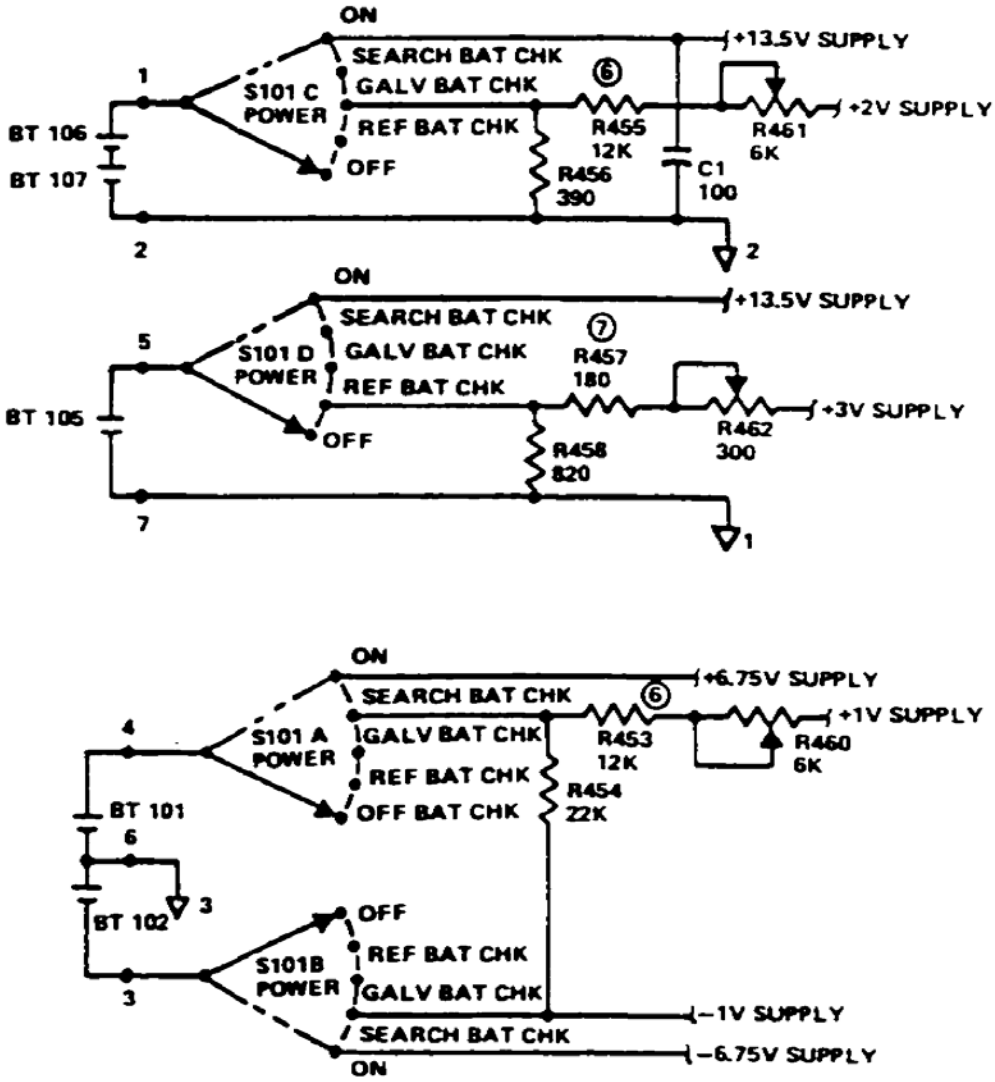


Figure 2-11. Battery check circuits

Learning Event 2:
DESCRIBE THE MODEL 1395 COAXIAL THERMAL CONVERTER

1. The Model 1395 Coaxial Thermal Converter set, (fig 2-12), is designed to provide accurate voltage measurements using AC/DC transfer techniques. Table 2-1 lists the ranges of each of the separate thermal converters included in the Model 1395 set. In addition, the electrical specifications and thermocouple characteristics are included.

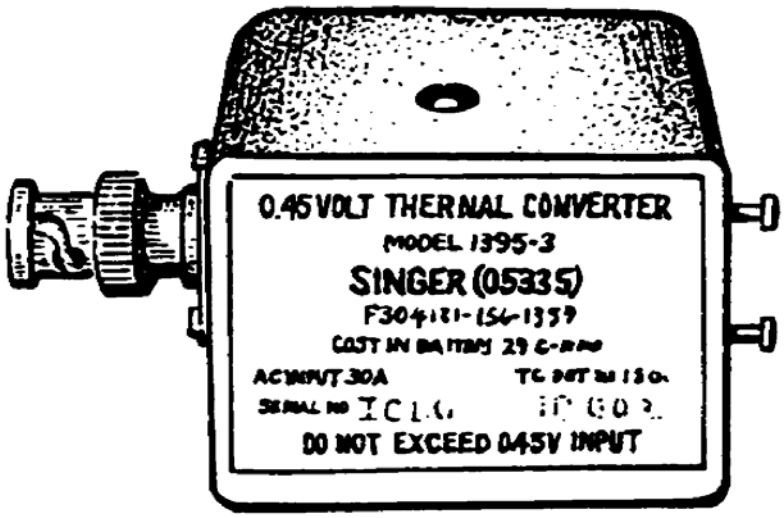


Figure 2-12. Model 1395 coaxial thermal converter set

Voltage Ranges:	Nominal Voltage:
Model 1395-1	3 Volts
Model 1395-2	1 Volt
Model 1395-3	0.3 Volts
Frequency Range:	DC to 10 MHz
Uncertainty of AC/DC Transfer Difference as supplied by NBS Calibration:	400 Hz to 50 kHz, ±0.1% 50 kHz to 1 MHz, ±0.2% 1 MHz to 10 MHz, ±0.4%
Input Resistance:	200 ± 10 ohms per nominal volt
Input Capacitance:	5 pf nominal
Thermocouple:	
Nominal heater current	5 mA
Max safe heater current	7.5 mA
Couple Output	7 mV ± 12% at nominal heater current
Couple Resistance	8 ohms ± 10%
Max AC/DC Reversal Error	0.04%

Table 2-1. Model 1395 specifications

2. As depicted in Figure 2-13, each Model 1395 consists of a stable, film-type resistor (R) in series with a high frequency thermocouple (TC). The combination is mounted coaxially in a cylindrical tube, the diameter of which is designed to provide a nearly transadmittance over a wide frequency range.

A UHF coaxial connector (J1) is provided for input and a G-R type connector (J2) is provided for thermocouple output. The thermocouple leads are not connected to the case in order to maintain signal isolation. Lower voltage probes have capacitive compensation (C) from the body of the resistor to ground to provide as flat a frequency response as possible.

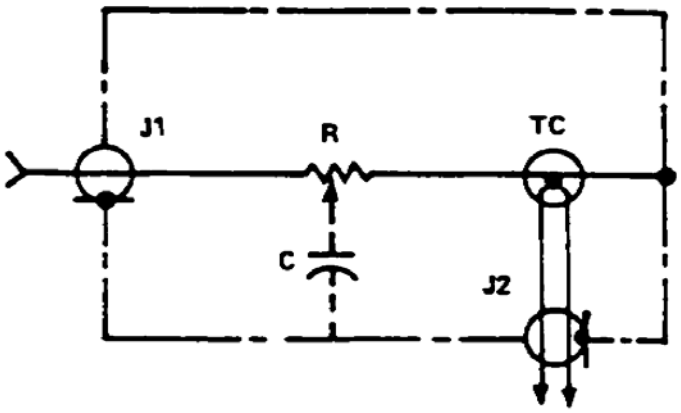


Figure 2-13. Model 1395 schematic

3. The thermocouple heater pf the Model 1395 can withstand continuous overloads of 50 percent (to 7.5 mA) and momentary overloads of 100 percent (to 10mA). Overloads greater than these can result in a permanent change of thermocouple characteristics or burnout of the heater. Burnout occurs so rapidly that the rise in DC couple output cannot be detected. Therefore it is necessary to take every precaution to avoid overloading the thermocouple.

a. Be sure the voltage being measured is reduced to its lowest value before connecting or disconnecting the Model 1395 input.

b. Provide a method for monitoring or controlling the voltage being measured.

c. Do not change the frequency of the voltage being measured without first reducing the voltage to its lowest value.

d. Do not allow the open-circuit DC couple voltage to exceed 16 millivolts (equivalent to 7.5 mA of heater current).

e. If reverse DC measurements are made, to eliminate the effect of reversal errors, the DC source must be operated ungrounded since one end of the thermocouple heater is grounded in the Model 1394.

4. Voltage measurements are made with the Model 1395 Coaxial Thermal Converters by using the principle of AC to DC transfer. An unknown AC voltage applied to the input of a Model 1395, chosen to have a voltage range appropriate for the measurement, will cause a rise in temperature of the thermocouple heater proportional to the RMS value of the AC voltage. This temperature rise will in turn produce a DC couple output proportional to the square

of the AC voltage. If the Model 1395 is now transferred to a source of DC voltage and this source is adjusted until the DC couple of the thermocouple is exactly the same value as it was when the AC voltage was applied, the resulting DC heater current is equal to the RMS AC heater current. Assuming a constant transadmittance of heater current to input voltage and no frequency errors in the thermocouple response, this DC input voltage is now exactly equal to the unknown AC voltage. Any measurement errors resulting from nonconstant transadmittance or thermocouple frequency response are expressed as the AC/DC transfer difference. Such errors can be corrected to obtain the best measurement accuracy.

5. To measure the RMS value of an unknown AC voltage, refer to the hookup diagram of Figure 2-14 and proceed as follows:

a. Select a Model 1395 whose voltage range includes the voltage to be measured. If the approximate value of the voltage is unknown, either obtain an approximate value from an auxiliary voltmeter or start the measurement process with the highest range Model 1395 and subsequently select lower range Model 1395s until the correct range is found.

b. Connect an appropriate DC monitoring instrument to the DC couple output of the Model 1395. This connection is made by a twin-contact shielded connector.

c. Reduce the level of the AC voltage to be measured to its lowest value.

d. Connect the unknown AC voltage to the coaxial input of the Model 1395.

e. Adjust the AC voltage to its desired level.

f. Note the indication of the DC monitor connected in step 1. For greatest accuracy allow 1 minute for the thermocouple to stabilize to a final output.

g. Reduce the level of the AC voltage.

h. Disconnect the input of the Model 1395 from the AC source.

i. Reduce the level of an appropriate DC source to its lowest level.

j. Connect the DC source to the coaxial input of the Model 1395.

k. Adjust the level of the DC source until the DC monitor indicates the same reading as obtained in step 6. For greatest accuracy, allow one minute for the thermocouple to stabilize to a final output.

l. Measure the value of the DC source. This value, corrected for any AC/DC transfer error, is the RMS value of the unknown AC voltage.

m. For greatest measurement accuracy, to eliminate the effects of DC reversal error in the thermocouple heater, steps i through 1 should be repeated with the opposite polarity of DC. Use the average of the two DC voltages, corrected for AC/DC transfer errors, to determine the RMS AC voltage.

n. Reduce the level of the DC source to its lowest level.

o. Disconnect the input of the Model 1395 from the DC source. This completes the measurement procedure.

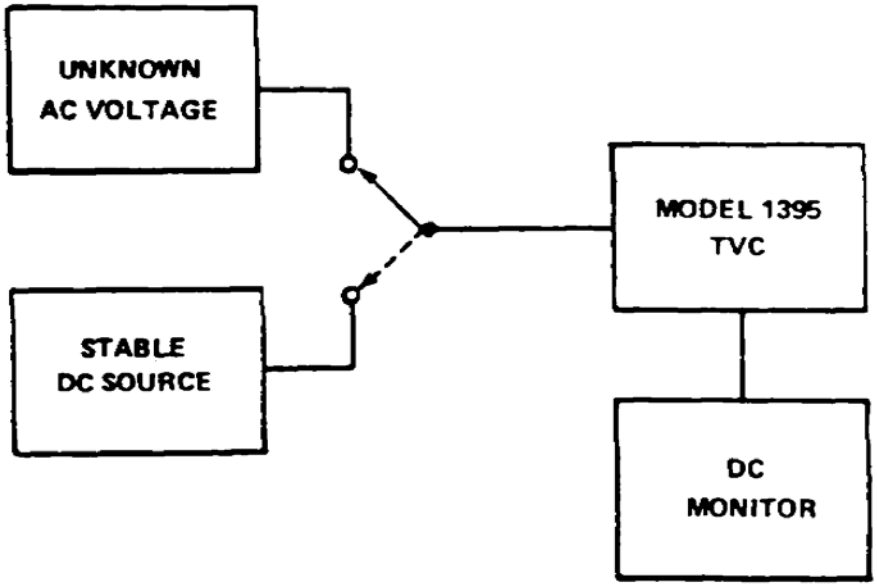


Figure 2-14. AC voltage measurement

Learning Event 3:
DESCRIBE THE MODEL B7842 THERMAL CONVERTER

1. The second set of thermal converters used at the secondary level is the Model B7842 (fig 2-15) which consists of the B7842-1, B7842-2, and the B7842-3. These thermal converters have a good frequency response from 5 Hz to 100 MHz. The maximum input voltage depends on the model; the B7842-1 has an input of 3 Vrms, the B7842-2 is 1 Vrms and the B7842-3 is 0.45 Vrms. The DC output voltage for full scale input to any of the three is a nominal 7.5 mV with an output impedance of less than 10 ohms. The input impedance is 50 ohms ± 0.15 ohm to 10 MHz and the AC-DC error is 6 percent to 10 MHz.

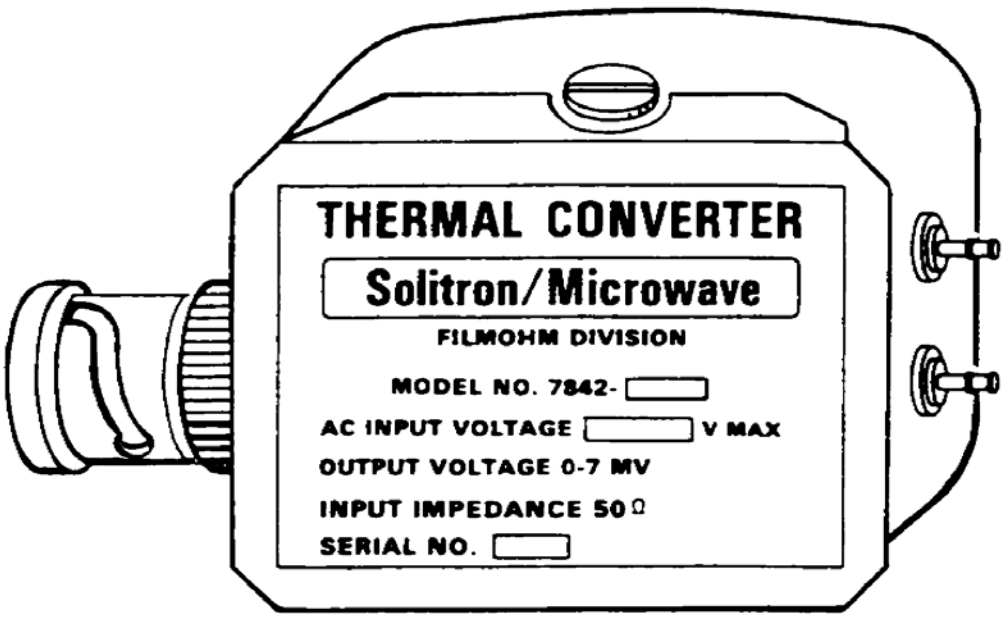
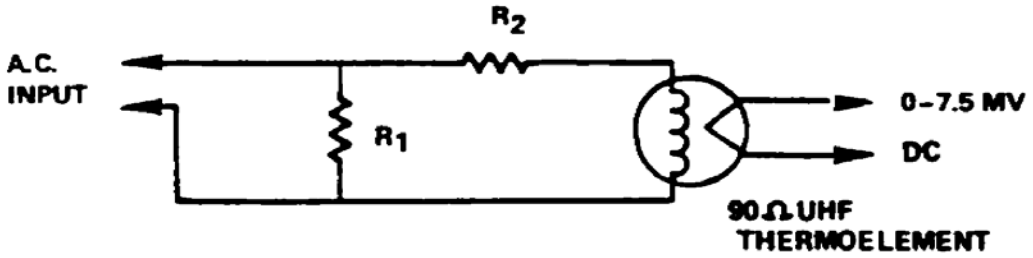


Figure 2-15. Model B7842 Thermal Converter

2. The schematic of the Model B7842 is shown in Figure 2-16. AC current into the 90-ohm UHF element heats the filament, heating the thermoelement junction which in turn generates a voltage proportional to the temperature of the filament. Thus the output voltage is proportional to the input power. Resistor R2 is used to obtain 5 mA current in the filament with the rated full input. Resistor R1 is used to trim the input impedance to 50 ohms. Operation of the Model B7842 is identical in procedure to that of the Model 1395 and will not be discussed.



MODEL	R_1 (APPROX)	R_2 (APPROX)
B7842-1	60Ω	510Ω
B7842-2	65Ω	114Ω
B7842-3	110Ω	0Ω

Figure 2-16. Model B7842 schematic

Lesson 2
PRACTICE EXERCISE

1. Which is not a basic part of a thermal transfer standard?

   a. Thermocouple
   b. Ammeter
   c. Galvanometer
   d. DC reference supply

2. When initially powering up the 540B, the thermocouple bead should be allowed to stabilize for _____?

   a. 45 minutes
   b. 30 minutes
   c. 15 minutes
   d. 10 minutes

3. Which battery should be replaced when the reference battery check indicates in the green area of the percent input meter?

   a. BT107
   b. BT106
   c. BT105
   d. BT102

4. What is the input voltage range of the Model 540B?

   a. 0.5 to 100 volts
   b. 0.5 to 1000 volts
   c. 1.0 to 100 volts
   d. 5.0 to 1000 volts

5. Refer to Figure 2-9. When a DC current is applied to the magnetic modulator, what should be the input to the meter circuit?

   a. A negative DC current
   b. A proportional AC current
   c. A 5 KHz signal
   d. A 5 KHz square wave

6. What should the Model 540B percent input meter indicate with a 15-volt signal applied on the 20 volt range?

   a. 15 volts
   b. 15 percent
   c. 25 percent
   d. 75 percent

7. Voltage measurements are made with the Model 1395 coaxial thermal converters by using what principle of transfer?

   a. AC to DC
   b. Low to high
   c. DC reversal
   d. AC reversal

8. The Model 540B polarity switch facilitates measurement of reversal error by reversing the _____?

   a. DC reference current
   b. Input to galvanometer
   c. Input to the thermocouple
   d. Input to the attenuator

9. What is the resistance of the Model 1395-1 to a .9v signal?

   a. 200 ± 10 ohms
   b. 160 ± 10 ohms
   c. 80 ± 10 ohms
   d. 80 ± 4 ohms

10. What is the maximum input voltage which can be safely applied to the Model B7842-2?

    a. 1 Vrms
    b. 2 Vrms
    c. 3 Vrms
    d. 4 Vrms

LESSON 3
DCLF REFERENCE STANDARDS

TASK

Describe the function and operation of each thermal reference standard and theoretically troubleshoot the 1600A Thermal Reference Standard.

CONDITIONS

Given the information and illustrations about theory and applications relating to DCLF reference standards.

STANDARDS

Demonstrate competency of the task skills and knowledge by correctly responding to at least 80 percent of the multiple-choice test covering theory and applications of thermal reference standards to include theoretical troubleshooting of the 1600A Thermal Reference Standard.

REFERENCES

None

Learning Event 1:
DESCRIBE THE MODEL 1600A THERMAL REFERENCE STANDARD

1. In the preceding lesson, you learned how to make very precise measurements of the DCLF voltages at the secondary transfer level by utilizing thermal transfer standards. The instruments discussed were very stable and accurate, making them suitable for a variety of applications. As you are aware, all calibration standards in the field of electronics require periodic calibration themselves and must be recertified in order to assure valid calibration of the items they support. Naturally, the calibration requires that the instruments used in the process must be more accurate than the item being calibrated. In other words, you wouldn't use a Model 260 Multimeter to certify a Model 3490A Digital Voltmeter.

2. To satisfy this need, the Model 1600A Autobalance AC/DC Transfer Standard and the Model NBS TVC Thermal Voltage Converter set are maintained at the calibration laboratory, both of which have directly traceable certification to the National Bureau of Standards. Additionally, the Model 1600A is specified for use in the calibration of the Model 332A/B DC Voltage Standard, Model 887AB Differential Voltmeter, Model 540B and Holt 6AR Thermal Transfer Standards, Holt 250 AC Ammeter Calibrator, and the Model 1394 Thermal Converters.

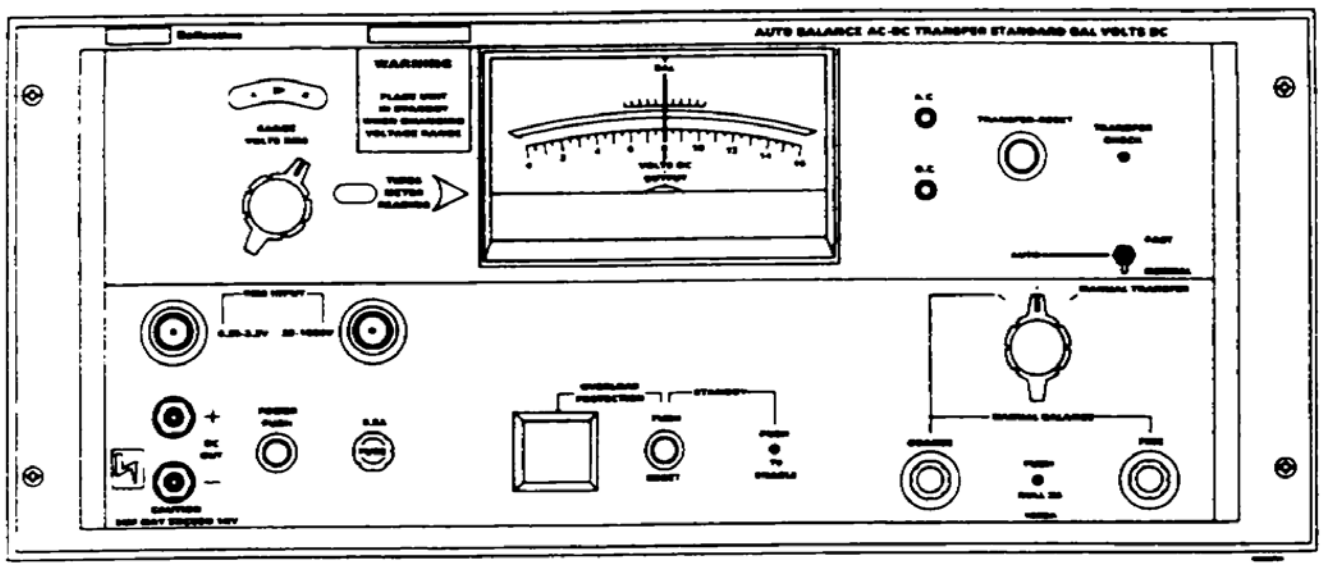


Figure 3-1. Model 1600A transfer standard

3. The Model 1600A Autobalance AC/DC Transfer Standard (ATS)(fig 3-1) is designed to permit a semi-skilled operator to make rapid and precise true RMS measurements of AC voltages with a minimum of operator participation, thereby reducing the possibility of human error. The ATS also has the ability to provide manual transfer and balancing measurements (i.e., orthodox AC/DC transfer standard operation). The applied signal under measurement is attenuated and applied to a thermoelement which produces a DC voltage proportional to the heating (RMS) value of the signal. An internally generated DC voltage having the same heating value is then substituted for the applied signal and this DC voltage is coupled to auxiliary readout instrumentation to provide a true RMS equivalent of the applied signal. The manual transfer mode of operation allows the operator to initiate the point in time at which the AC to DC transfer occurs and, in some instances, allows more accurate measurements than is possible in the automatic mode. The manual balance mode requires the operator to manually balance the unit and, while being somewhat more time-consuming, it is still a rapid operation and permits highest accuracy measurements down to 2 Hz.

a. The ATS is a semiautomatic AC/DC transfer standard which provides a DC output voltage equal to the true RMS value of complex (i.e., pulsed, square-wave, triangular-wave and other nonsinusoidal signals having crest factors of up to 10:1) or sinusoidal signals. The DC output voltage generated is applied to an auxiliary readout instrument, such as a DC differential or DC digital voltmeter, which indicates the DC RMS equivalent of the applied input voltage.

4. The ATS employs the same thermoelement and coaxial attenuators for sensing both the applied AC signal and the internally developed balancing voltage, thereby eliminating problems due to mismatch. Both the attenuators and the thermally lagged thermoelement are housed in compartments of an easily removable transfer assembly (Model 11600A - see fig 3-2). Removal of the transfer assembly from the Model 1600A mainframe permits its use as a conventional AC/DC transfer standard and also permits its shipment to IBS for reports on AC/DC differences with an uncertainty of less than 0.005 percent (to 20 kHz) and 0.01 percent (up to 50 kHz).

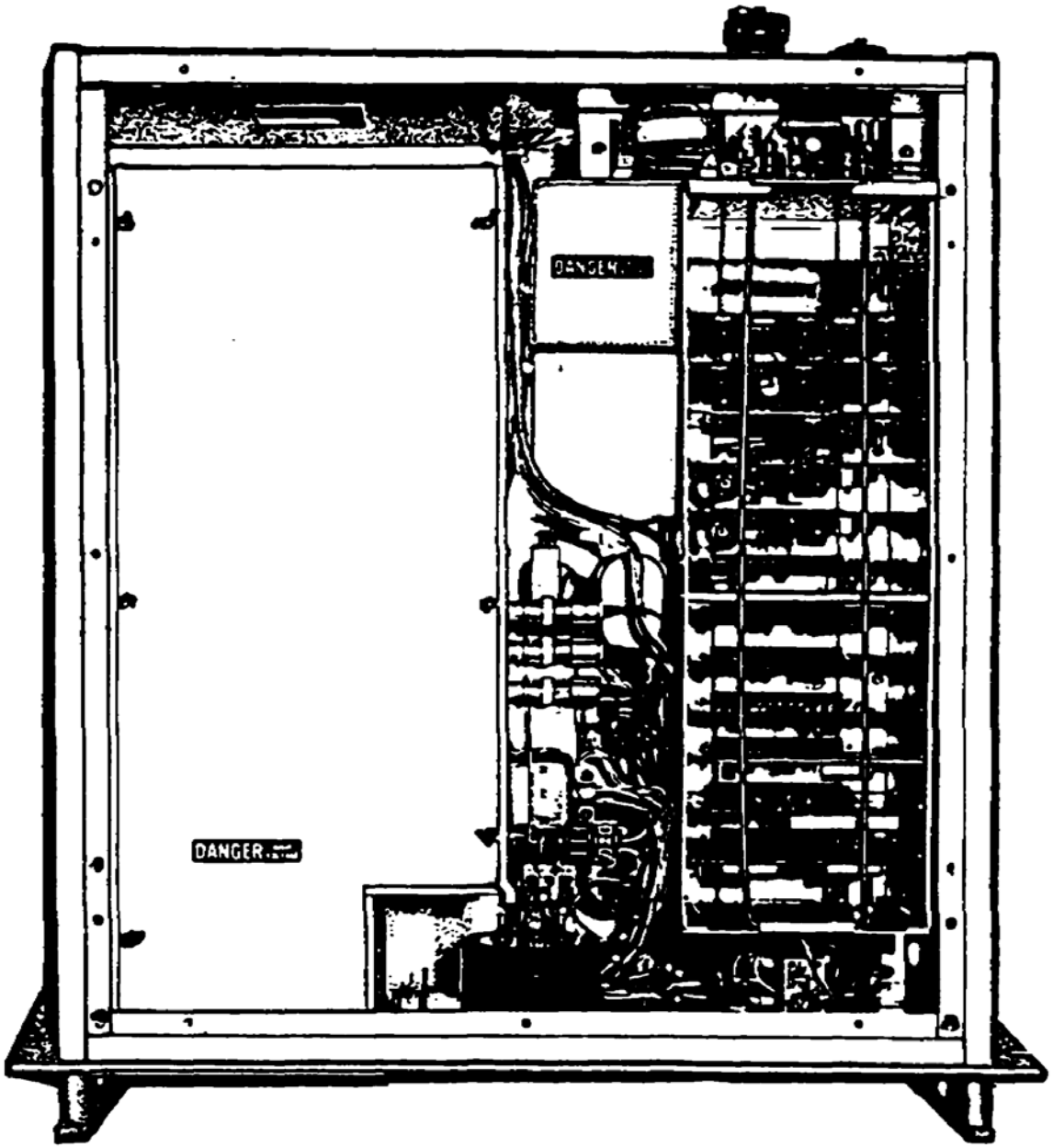


Figure 3-2. Model 11600A Transfer Assembly

a. A positive action peak-sensing overload system that does not clip the input signal is incorporated in the ATS. This feature eliminates the possibility of erroneous measurements due to undetected clipping or shunting of the applied signal. A nonlocking pushbutton switch is provided to permit removal of the overload protection capability when measuring signals having a crest factor greater than 2:1 and to optimize accuracy when measuring signals above 100 kHz.

b. A 12-position range selector switch, in conjunction with the internal attenuators, enables the measurement of input voltage levels from 0.25 to 1000 volts. Since the thermoelement has a square-law response, the range selection technique employed ensures that the equipment will not balance when the thermoelement driving current falls below approximately one-half the rated level of 5 mA. This design consideration assures good signal-to-noise ratios for all measurements. A 13th switch position provides selection of external remote range programming.

c. When ATS is operating in the automatic transfer mode, special circuitry prevents automatic transfer until the thermoelement EMF output rate of change is 0.002 percent/second or less. This ensures against inaccurate measurements resulting from the thermoelement not having reached equilibrium. A normal transfer is accomplished typically in 10 seconds; however, when there is a large change in heater current, the time required for the thermoelement to reach stable balance is extended, resulting in a somewhat longer measurement time. When the ATS is operated in the manual transfer mode, the instant of transfer is manually determined. In manually balanced operation, the operator adjusts the level of the internal balancing voltage until a null indication is obtained and then achieves transfer by manual switching.

d. The controls, connectors, and indicators required for operation of the ATS are illustrated in Figure 3-3 and their functions are described in Table 3-1. Carefully study both to thoroughly familiarize yourself with the instrument before proceeding. The ATS is a relatively simple instrument to operate; however, there are a number of "tips" and precautions to become familiar with. Some of these are similar to those discussed in Lesson 2 for the Model 540B, while others are unique to the ATS.

(1) If the voltage range of the applied signal is known, the operator need only set the RANGE VOLTS switch to the appropriate position and couple the voltage to be measured to either the AC INPUT 0.25V or AC INPUT 32-1000V connector, as required.

(2) Should the signal be of unknown level, employ the conventional voltmeter technique of setting the RANGE VOLTS switch to the highest voltage range (500 to 1000) and couple the signal to be measured to the AC INPUT 32-1000V connector. If balance cannot be achieved, the operator should increase the sensitivity of the ATS, switching input connectors when required, until a balance is achieved.

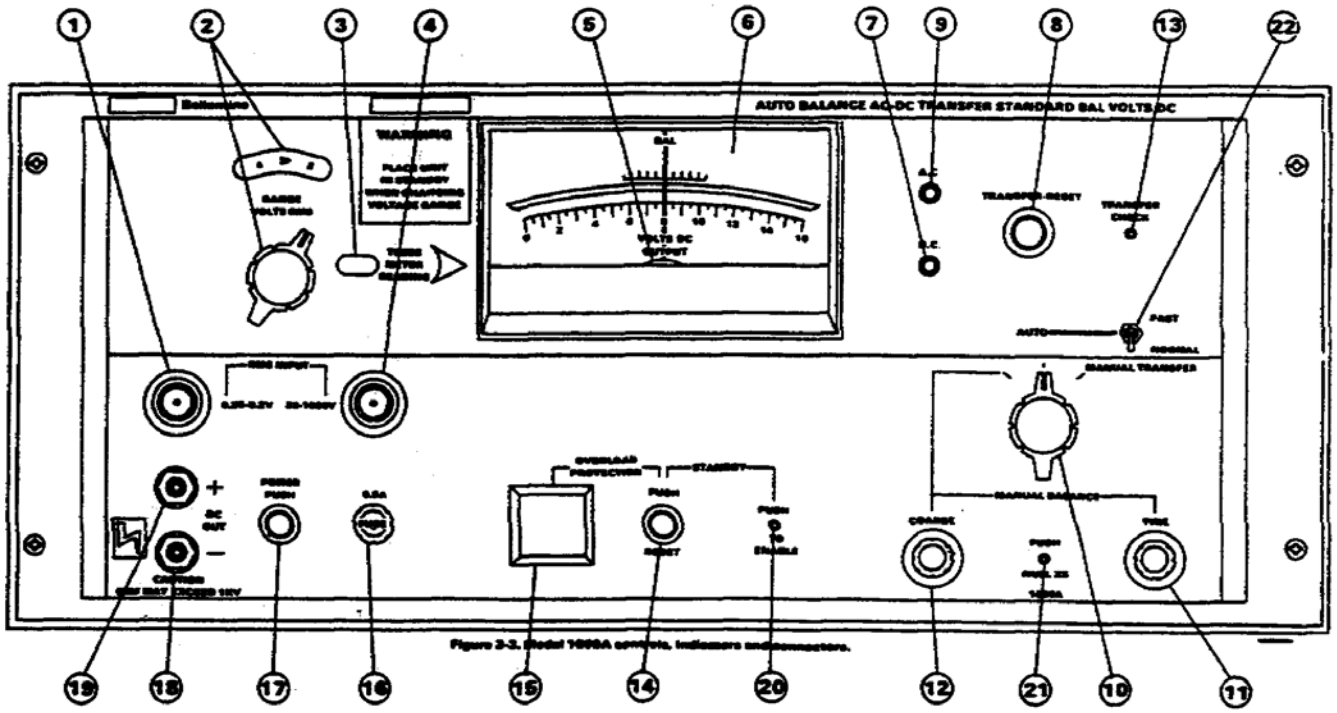


Figure 3-3. Model 1600A controls, indicators and connectors

(3) The ATS is designed to measure the RMS value of stable AC voltages. Should the AC indicator light remain illuminated and/or the front panel meter continuously "hunts" or "slews" when the ATS is operated in either the AUTOMATIC or MANUAL TRANSFER mode, it is likely that the applied signal is unstable. To judge the stability of the applied signal, the operator should switch to the manual balance mode and attempt to null the meter using the MANUAL BALANCE COARSE and/or FINE controls. If a balance condition cannot be maintained, the applied signal is fluctuating too rapidly to permit a measurement of specified accuracy to be made. Under these conditions the measurement should be made in the manual balance mode and the reduced accuracy (due to the fluctuation of the signal) should be noted. In AUTO transfer use FAST mode for input signals drifting less than 0.005 percent/second.

Figure 3-3 Index No.	Control, Indicator or Connector	Function
1	AC INPUT 0.25-32V connector A1J5	Connector employed when RANGE VOLTS switch is set to measure applied voltages between 0.25 and 32 volts rms. Connector is General Radio 874 series.
2	RANGE VOLTS switch A1S3 and dial (13 position rotary switch)	Permits operator to select any one of 12 voltage measurement ranges as indicated on dial 0.25 to 0.5 volts 0.5 to 1.0 volts 1 to 2 volts 2 to 4 volts 4 to 8 volts 8 to 16 volts 16 to 32 volts 32 to 64 volts 64 to 125 volts 125 to 250 volts 250 to 500 volts 500 to 1000 volts A 13th range enables remote range programming. (PGM)
3	TIMES METER READING dial	Provides factor which, when multiplied by the front panel meter DC OUTPUT VOLTAGE scale indication, enables the operator to determine (within 5%) the rms value of the applied signal after AC to DC transfer.
4	AC INPUT 32-1000V connector A1J6	Connector employed when RANGE VOLTS switch is set to measure applied voltages between 32 and 1000 volts rms. Connector is General Radio 874 series.
5	Mechanical zero adjustment screw	Permits mechanical zero-setting of meter pointer at BAL center line when power is disconnected.
6	Meter M1	Indicates proximity to null condition (0 on BAL scale) when AC indicator is illuminated and mode switch is set to MANUAL BALANCE, AUTO or MANUAL TRANSFER; indicates d-c output voltage (on DC OUTPUT VOLTAGE scale) within 5% when DC indicator is illuminated.
7	AC Indicator DS1	Illuminates when ATS is in a-c balancing state (i.e., applied signal being automatically or manually nulled).
8	TRANSFER RESET switch S4 (Pushbutton)	When mode switch is set to MANUAL BALANCE or MANUAL TRANSFER, permits the operator to switch between a-c balancing and d-c output states; when mode switch is set to AUTO, permits operator to recycle ATS for another measurement.
9	DC Indicator DS2	Illuminates when ATS is in d-c output state (i.e., d-c equivalent of applied signal rms voltage is being furnished at DC OUTPUT binding posts).

Table 3-1. Controls, indicators, and connectors

Figure 3-3 Index No.	Control, Indicator or Connector	Function
10	Mode switch S1 (3 position Rotary switch)	Permits operator to select operating mode: MANUAL BALANCE – operator must manually balance null meter before manually transferring to d-c output state; AUTO – ATS automatically nulls and switches to d-c output state; MANUAL TRANSFER – ATS automatically nulls but operator must manually switch to d-c output state.
11	MANUAL BALANCE FINE control R2 (10 Turn Control)	Permits vernier adjustment of nulling voltage, when operating in manual balance mode.
12	MANUAL BALANCE COARSE control R1 (10 Turn Control)	Permits coarse adjustment of nulling voltage when operating in manual balance mode.
13	TRANSFER CHECK switch S5 (Mom. Pushbutton)	Provides a quick check for the nulling circuitry when ATS is in the d-c output state (i.e., DC Indicator illuminated). Depression of the switch should cause the front panel meter to indicate nearness to null when in the d-c output state.
14	OVERLOAD PROTECTION PUSH TO RESET pushbutton switch/indicator S2/DS3 (pushbutton)	Illuminates when an overload has occurred. Momentary depression of the switch resets the overload protection circuitry. Note that if the overload remains or the indicator lamp within the switch fails, the circuitry cannot be reset.
15	OVERLOAD PROTECTION PUSH TO DISABLE pushbutton switch S3 (Momentary pushbutton)	When held depressed, disables the overload protection capability. This feature permits the measurement of a-c signals having a crest factor of up to 10:1 and optimizes accuracy above 100 KHz.
16	0.5A fuseholder A1XF1	Line fuse. 0.5A 3AG Slo-Blo
17	POWER PUSH pushbutton switch/ indicator A1S1/A1DS1	Controls application of line power to ATS. When equipment is coupled to line power and switch is depressed, indicator will illuminate.
18	–DC OUTPUT binding post A1J2	Common (ground) d-c output terminal.
19	+DC OUTPUT binding post A1J1	Positive d-c output terminal.
20	STANDBY switch S6 (Momentary pushbutton)	Disconnects input by opening attenuator thru overload circuit activation. Operates only in AC mode.
21	NULL X5 switch S9 (momentary pushbutton)	Increases Null resolution by factor of five to 10 ppm (0.001%).
22	FAST/NORMAL switch S7 (Double throw toggle switch)	Operates in Auto Balance modes to provide NORMAL high accuracy transfer on steady signals or FAST transfer when signals have amplitude drift < 0.005% per second.

Table 3-1. Controls, indicators, and connectors (cont.)

Control, Indicator or Connector	Function
REAR PANEL CONNECTORS AND SWITCHES NOT SHOWN IN FIGURE 3-3	
115V-230V switch A1S2 on 11601A Transfer Assembly	Enables ATS to operate from either a 115-volt or 230-volt a-c line.
Line Power Receptacle on 11601A Transfer Assembly	Receptacle for 3 wire power cable 33100000A.
Remote programming connector J14 (7 Pin MS Connector)	Permits operation of the ATS (in AUTOmatic mode) from a remote location. Requires jumper connecting pins per Table 2-2 in local operation.
AUTO RECYCLE switch S8 (2 position slide switch)	Provides for automatic reset to AC in AUTO mode after 45 second waiting period after transfer from AC to DC. Also provides for manual reset operation from front panel or remote programmer.
Remote thermo converter connector J15 (10 Pin MS Connector)	Permits operation of external thermal converter from ATS. Also provides access to thermo element couple output emf during calibration. Requires jumper connecting pins per Table 2-2 in local operation.
Remote DVM range command and trigger output Connector J16. (50 pin Blue Ribbon)	Permits range tracking of remote dc readout DVM with ATS range switch A1S3. Also provides DVM "read" trigger 10 seconds after ATS transfer to DC.
Remote ATS Range Programming Input connector J300. (Option 03) (50 pin Blue Ribbon)	With option 03 permits remote ranging of ATS range switch A1S3 when latter is in PGM position.

Table 3-1. Controls, indicators, and connectors (cont.)

e. Various sources of error may be present when employing the ATS. These sources are detailed below so that the user may be familiar with them and allow for them to obtain maximum accuracy.

(1) Loading effects. The input impedance of the ATS, particularly on the low voltage ranges, is relatively low (due to the current required for the thermoelement heater and the shunt input capacity presented by the relay connected range attenuator) and will have a loading effect when connected to the voltage source under test. Voltage sources having a nonzero output impedance and/or poor regulation characteristics will develop two different output levels; one while the ATS is in the AC balancing state (loading the source) and a second when the ATS is in the DC transfer state (voltage source removed from ATS input attenuator). The output voltage of the ATS, as indicated on the readout instrument, will be the voltage of the loaded source.

(2) Losses in interconnecting wiring. Since the ATS has an output impedance of approximately 200 ohms/volt, the voltage drop in the wiring interconnecting the voltage source and the ATS may introduce a measurement error, particularly when the low voltage ranges are employed. It is recommended that short heavy leads be employed when interconnecting the equipment.

(3) Thermal EMF in DC output system. Nonsimilar conductors employed to couple the DC OUTPUT binding posts to the readout instrument will introduce thermal EMFs. It is recommended that conductors of the same material (copper) be employed.

(4) Settling time. When the ATS transfers from the AC balancing state to the DC output state in the AUTO mode, the internal DC substitution voltage builds up to balance the voltage stored in the digital memory circuit. The operator should allow approximately 15 seconds to elapse before reading the DC output voltage.

(5) Stability. Due to inherent temperature-dependent drift in the thermoelement output (0.01 percent/minute after a 10-minute warmup), the ATS output voltage should be measured as soon as the instrument has "settled" in the DC output mode. If a potentiometer system or differential voltmeter is employed as the readout instrument, balance the readout instrument as closely as possible after the ATS has transferred to the DC output state. Repeat the measurement cycle a second time and then null the readout instrument. Note that, for maximum DC output stability, the ATS should be allowed to warmup for at least four hours before measurements are made.

(6) Auto-zero. The 1600A Auto Balance AC/DC Transfer Standard incorporates circuitry which automatically transfers from the signal input AC measuring mode to the DC output read mode. The ideal DC read time occurs some 15 seconds after transfer since the same thermal conditions occur in the DC transfer system as existed at the AC measuring point at which the transfer was initiated.

(a) Making a DC reading too early does not provide the DC transfer voltage loop time to reach stable equilibrium required for repeatable 100 ppm measurements. Waiting too long (more than 20 seconds) causes changes in the thermal equilibrium and thermal drifts which will cause additive errors to accrue to the transfer DC reading.

(b) It is advisable to read the DC transfer voltage on the 15-second basis. Although the thermocouple is suitable "thermally lagged" and low temperature coefficient metal film multiplier resistors are used, remember that the thermal transfer standard is basically a "thermal" sensing instrument. The extreme sensitivity of the 1600A can resolve ambient changes of as little as 20 millidegrees Celsius and the transfer DC output reading should be made within the time constraints indicated above to assure specified transfer accuracy. These read-out timing conditions apply equally to the AUTO, MANUAL BALANCE, and MANUAL TRANSFER operating modes.

(c) The 1600A is thermally lagged to provide precise, accurate, and repeatable transfer measurements within the timing constraints indicated. To certify readings, it is recommended that three to four transfer readings are made. Delete the first reading and average the remaining readings for best results. It is recommended that the AUTO operating mode be used in recycle mode to make continuous AC/DC/AC transfer measurements.

(d) Slide switch S8 is located on the rear panel of the 1600A. When set to OFF position, the front panel RESET pushbutton initiates switch to AC mode. When S8 is set to ON, the reset from DC to AC is automatically recycled approximately 30 seconds after transfer from AC to DC mode. This continuous recycle adds an auto-zero feature to the auto balance mode which avoids transfer errors caused by long-term thermal variations.

(e) It is recommended that AUTO mode is always used with switch S8 in auto-zero recycle mode.

(7) Attenuator heating. When measuring voltages between 250 and 1000 volts, the power dissipated by the input attenuators will produce a slight change in resistance. It is recommended that the MANUAL TRANSFER mode be employed when measuring such voltages and that transfer be made after the signal under measurement has been applied for approximately two minutes (allowing the input attenuator resistance to stabilize).

(8) Repeatability. Lack of perfect repeatability is due to internal noise, finite digital memory resolution, contact resistance in switches and relays, thermal effects on attenuators, etc. Since these error sources are random in nature, several measurements should be made and the results averaged to obtain ultimate accuracy.

f. The ATS has three modes of operation, each selected by the setting of the front panel switch. When the switch is set to MANUAL BALANCE, the operator manually adjusts the MANUAL BALANCE COARSE and/or FINE controls until a null (O on the meter BAL scale) is attained. After transfer, the voltage at the DC OUTPUT binding posts will be equal to the RMS value of the applied AC signal. While this mode of operation provides the greatest measurement accuracy (due to the finite resolution of the digital memory circuitry in the AUTO mode), it is slightly more time consuming although substantially faster than conventional AC-DC transfer standard measurements. When the mode switch is set to AUTO or MANUAL or MANUAL TRANSFER, the ATS balances automatically. In the AUTO mode, AC to DC transfer is performed automatically, while in the MANUAL TRANSFER mode the AC to DC transfer point is determined by the operator. Manual transfer mode is used for moderately unstable input signals.

g. The ATS can be employed as a voltmeter to provide a relatively coarse indication of applied signal levels. When the instrument is operated in either the automatic or manual transfer mode, the DC equivalent of the applied AC signal RMS level can be read by multiplying the meter DC OUTPUT VOLTAGE scale indication by the factor specified on the TIMES METER READING dial after transfer has been achieved. The voltage thus obtained will be within ±5 percent of the true RMS level of the input signal.

h. An overload protection capability is provided which will automatically remove the applied signal from the attenuator/thermoelement circuitry whenever the peak value of the applied signal exceeds 175 percent of the selected range high voltage peak. So, if the RANGE VOLTS switch is set to 125 to 250 and the peak value of the applied signal is in excess of 437 volts

(although its RMS value is between 125 and 250 volts), the overload protection circuitry will be triggered. The OVERLOAD PROTECTION PUSH TO RESET pushbutton switch will illuminate to indicate that an overload condition was and/or is present. The ATS will not be capable of measurement until the overload condition was and/or is present. The ATS will not be capable of measurement until the overload condition has been corrected (i.e., setting the RANGE VOLTS switch to a higher range and depressing the OVERLOAD PROTECTION PUSH TO RESET pushbutton switch indicator).

(1) The overload protection circuitry is normally not intentionally disabled unless signals having a high crest factor (greater than 2:1) are being measured. When such signals are applied to the ATS, the overload protection circuitry (if not disabled) would remove the input when the signal peak value is greater than 175 percent of the selected range RMS high limit. When the RMS level of the applied signal will not damage either the attenuator or thermoelement, the overload protection circuitry may be disabled by holding the OVERLOAD PROTECTION PUSH TO DISABLE pushbutton switch depressed for the duration of the measurement.

(2) A standby mode is provided to eliminate the possibility of damaging the thermoelement when changing input cables or switching signal levels. Standby switch S6 is provided to activate the overload protection circuit and disconnect the input from the attenuator. S6 is activated by depressing a momentary pushbutton switch on the front panel. It functions only when the ATS is in the AC mode. The overload lamp DS3 lights to show standby operation. When ready to resume normal operation the overload protection reset switch S2 is pushed to reconnect the input connectors to the attenuator.

Learning Event 2:
EXPLAIN THE MODEL 1600A OPERATION MODES

1. To operate the ATS in the manual balance mode, proceed as directed in the following steps:

a. Couple the ATS to line power and momentarily press the POWER PUSH pushbutton switch; the indicator portion of the switch should illuminate. Allow the ATS to warm up for at least 20 minutes.

b. Set the mode switch to MANUAL BALANCE.

c. Set the RANGE VOLTS switch to obtain a dial indication of 500 to 1000. Push the STANDBY pushbutton and note that the overload lamp is illuminated.

d. Interconnect the equipment as illustrated in Figure 3-4, coupling the voltage source under measurement to the AC INPUT 32-1000V connector. Set input voltage and RANGE VOLTS switch into range.

e. Note which indicator (AC or DC) is illuminated. If the DC indicator is illuminated, momentarily press the TRANSFER-RESET pushbutton switch. The AC indicator will illuminate and the DC indicator will extinguish.

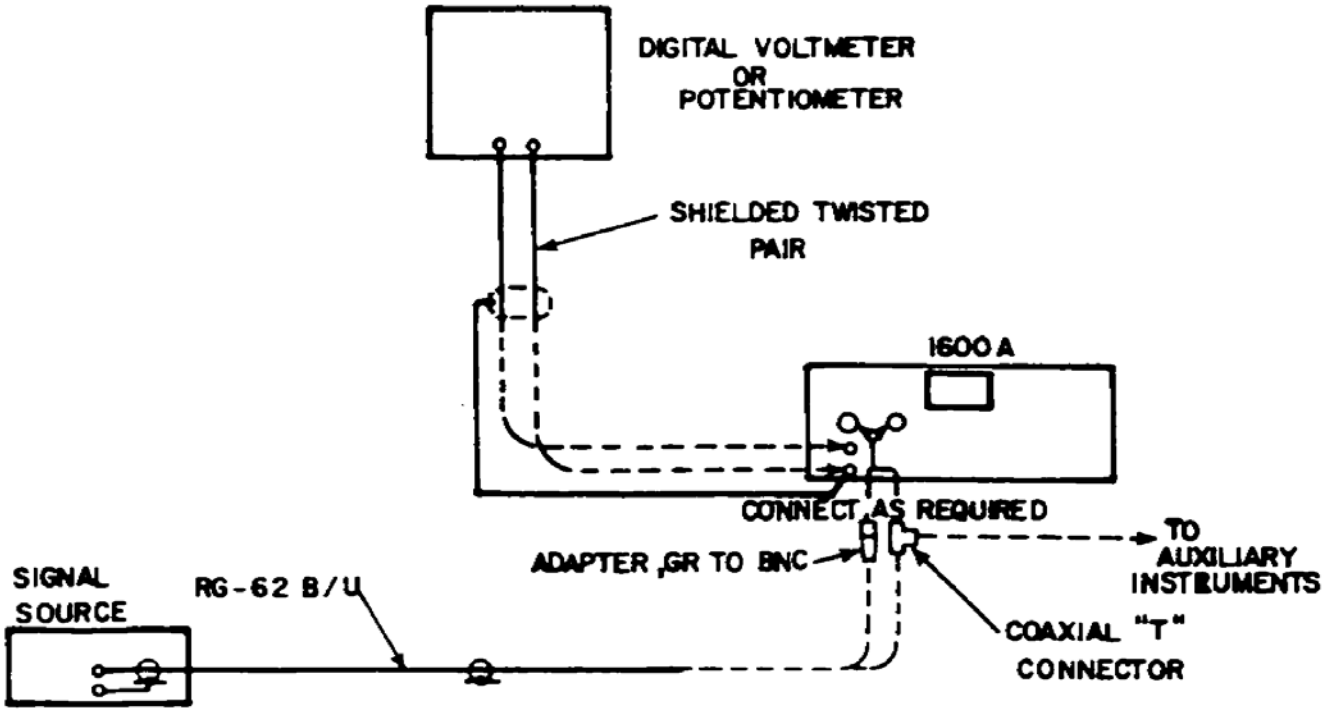


Figure 3-4. Equipment interconnection diagram

f. Note if the OVERLOAD PROTECTION PUSH TO RESET indicator is illuminated. If it is, momentarily depress the OVERLOAD PROTECTION PUSH TO RESET pushbutton switch. The indicator will extinguish.

g. Adjust the MANUAL BALANCE COARSE and/or FINE controls to obtain a meter indication of 0 on the BAL scale. When this indication is obtained, the ATS is ready to be set to the DC output state. To increase resolution at balance, push NULL X5 pushbutton. This gives maximum resolution of 10 ppm per minor scale division.

h. Momentarily depress the TRANSFER-RESET pushbutton switch to place the ATS in the DC output state; the DC indicator should illuminate. A DC output voltage equivalent to the RMS value of the signal under measurement can be obtained from the indication of the digital VM or potentiometer connected between the +DC OUTPUT and -DC OUTPUT binding posts. Note that a less

accurate reading can be obtained by noting the meter DC OUTPUT VOLTAGE scale indication and multiplying this value by the factor indicated in the TIMES METER READING dial.

2. To operate the ATS in the reverse manual balance mode (i.e., using the ATS to provide a reference output level and then setting the RMS value of the applied signal to equal this voltage), proceed as follows:

a. Couple the ATS to line power and momentarily depress the POWER PUSH pushbutton switch; the indicator portion of the switch should illuminate. Allow the ATS to warmup for at least 20 minutes.

b. Set the mode switch to MANUAL BALANCE.

c. Set the RANGE VOLTS switch to obtain the desired voltage and note which indicator (AC or DC) is illuminated. If the AC indicator is illuminated, momentarily depress the TRANSFER-RESET pushbutton switch; the AC indicator will extinguish and the DC indicator will illuminate.

d. With the voltage source set for minimum output level, interconnect the equipment as illustrated in Figure 3-4.

e. Adjust the MANUAL BALANCE COARSE and/or FINE controls until the desired RMS voltage level (as indicated on the DC digital voltmeter) or potentiometer null is obtained.

f. Without further adjustment of either the MANUAL BALANCE COARSE and/or FINE control, momentarily depress the TRANSFER RESET pushbutton switch; the DC indicator will extinguish and the AC indicator will illuminate.

g. Carefully adjust the output level of the voltage source until the pointer of the ATS meter deflects to an indication of 0 on the BAL scale. When this occurs, the voltage source output level has been set to the desired value.

3. To operate the ATS in the automatic balance mode, proceed as directed in the following steps:

a. Couple the ATS to line power and momentarily depress the POWER PUSH pushbutton switch; the indicator section of the switch should illuminate. Allow the ATS to warm up for at least 20 minutes. Set the auto recycle slide switch S8 on the rear panel to "OFF".

b. Set the mode switch to AUTO; the AC indicator will illuminate. Set the NORMAL/FAST toggle switch to NORMAL.

c. Set the RANGE VOLTS switch to obtain a dial indication of 500 to 1000. Push the STANDBY pushbutton and note that the overload lamp is illuminated.

d. Interconnect the equipment as illustrated in Figure 3-4, coupling the voltage source under measurement to the AC INPUT 32-1000V connector. Set input voltage and RANGE VOLTS switch into range.

e. Note that the OVERLOAD PROTECTION PUSH TO RESET indicator is illuminated. If it is, momentarily depress the OVERLOAD PROTECTION PUSH TO RESET pushbutton switch. The indicator should extinguish.

f. After approximately 15 seconds, the meter pointer will deflect to an indication of 0 on the BAL scale. At this time the AC indicator will extinguish and the DC indicator will illuminate. A DC output voltage equivalent to the RMS value of the signal under measurement can be obtained from the indication of the DC digital voltmeter or other readout instruments connected between the +DC OUTPUT and -DC OUTPUT binding posts. Note that a less accurate reading can be obtained by noting the meter DC OUTPUT VOLTAGE scale indication and multiplying this value by the factor indicated in the TIMES METER READING dial.

4. To operate the ATS in the manual transfer mode, proceed as directed in the following steps:

a. Couple the ATS to line power and momentarily depress the POWER PUSH pushbutton switch; the indicator section of the switch should illuminate. Allow the ATS to warmup for at least 20 minutes.

b. Set the RANGE VOLTS switch to 500 to 1000.

c. Set the mode switch to MANUAL TRANSFER and note which indicator (AC or DC) is illuminated. If the DC indicator is illuminated, momentarily depress the TRANSFER RESET pushbutton switch; the DC indicator will extinguish and the AC indicator will illuminate. Push the STANDBY pushbutton and note that the overload lamp is illuminated.

d. Interconnect the equipment as illustrated in Figure 3-4, coupling the voltage source under measurement to the AC INPUT 32-1000V connector. Set the input voltage and RANGE VOLTS switch into range.

e. Note that the OVERLOAD PROTECTION PUSH TO RESET indicator is illuminated. If it is, momentarily depress the OVERLOAD PROTECTION PUSH TO RESET pushbutton switch; the indicator section of the switch should extinguish.

f. After approximately 15 seconds, the meter pointer will deflect to an indication of 0 on the BAL scale. When the pointer comes to rest within one-half division of 0, momentarily depress the TRANSFER RESET pushbutton switch. At this time, the AC indicator will extinguish and the DC indicator will illuminate. A DC output voltage equivalent to the RMS value of the signal under measurement is available at the DC OUTPUT binding posts and can be read by means of the DC digital voltmeter or potentiometer. Note that an approximate reading may be obtained by noting the meter DC OUTPUT scale indication and multiplying this value by the factor indicated in the TIMES METER READING dial; this feature permits presetting of differential voltmeter or potentiometer controls.

5. External thermal converters, such as the Model 1395, may be used with the ATS for extended frequency range to 1 GHz. The ATS is set up for this mode of operation simply by removing P15 and J15 at the rear panel and connecting a suitable cable between J15 and the thermal converter DC output (fig 3-5). To make a transfer reading, connect the unknown AC source being measured to the input of the thermocouple. Balance the AC loop in the usual way, depending on the mode of operation of the 1600A. When the DC transfer has taken place, disconnect the unknown AC source from the thermocouple and quickly connect the free end of the DC output cable to the thermocouple. Allow 10 to 15 seconds for the DC loop to stabilize and read the DC voltage on the DVM.

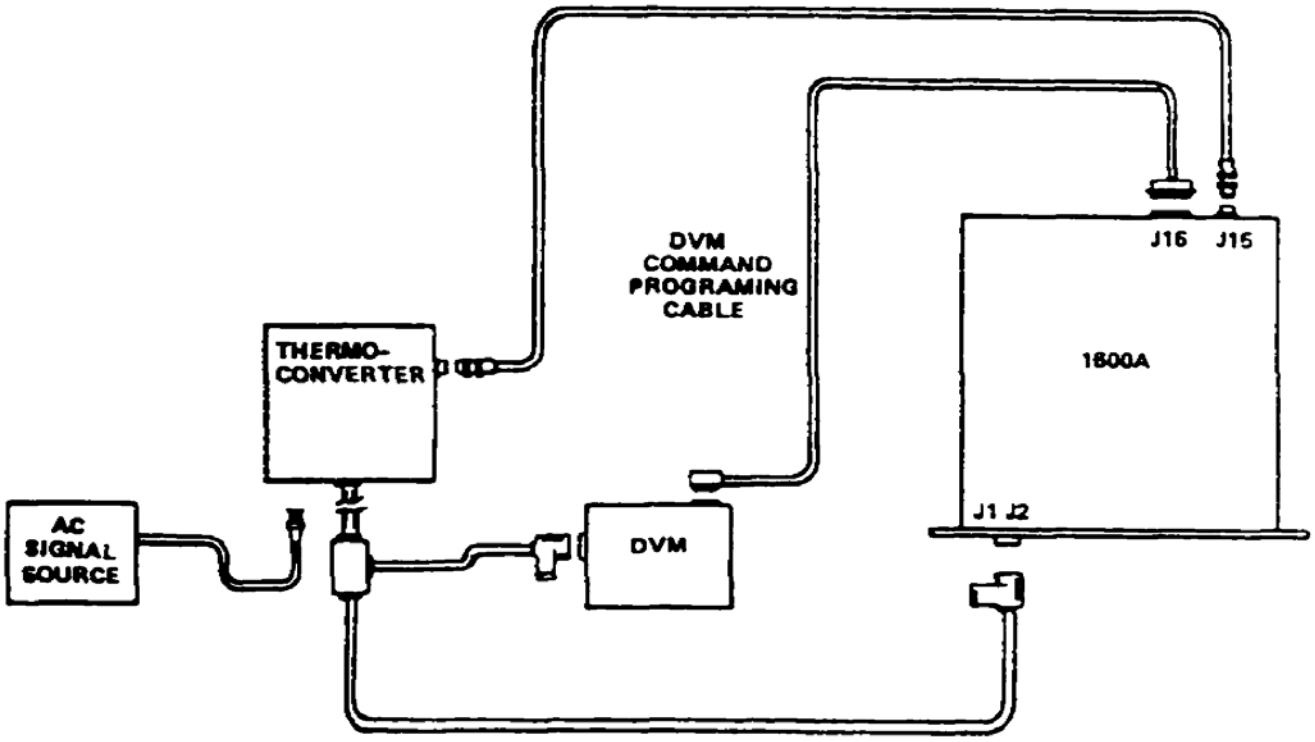


Figure 3-5. External thermal converter connection

Learning Event 3:
DESCRIBE THE MODEL 1600A CIRCUIT

1. The Model 1600A block diagram is shown in Figure 3-6. The ATS consists of 15 major functional circuits interconnected as shown in the block diagram. AC signals to be measured are applied to one of two AC INPUT connectors, depending on the signal level, and are coupled to the removable transfer assembly which contains attenuators, a thermoelement, and an overload protection circuit. Figure 3-7 is a simplified representation of the input circuitry. The low and high voltage attenuators are fixed resistance which are paralleled by changing the range switch setting to vary their series resistance. This prevents the voltage coupled to the thermoelement heater from exceeding its maximum voltage rating of approximately 0.45 volts rms.

a. The overload protection circuit is located between the attenuator output and the thermoelement heater to disconnect the applied signal from the attenuator should the signal be greater than the measurement range selected by the range volts switch.

b. The thermoelement, being an RMS device, develops a DC output related to the RMS value of the attenuated input signal. Since the thermoelement has a maximum output level of approximately 7 millivolts, this low-level DC voltage is chopped and fed to an amplifier. The use of a chopper/amplifier eliminates the drift problems normally associated with the measurement of low-level DC voltages.

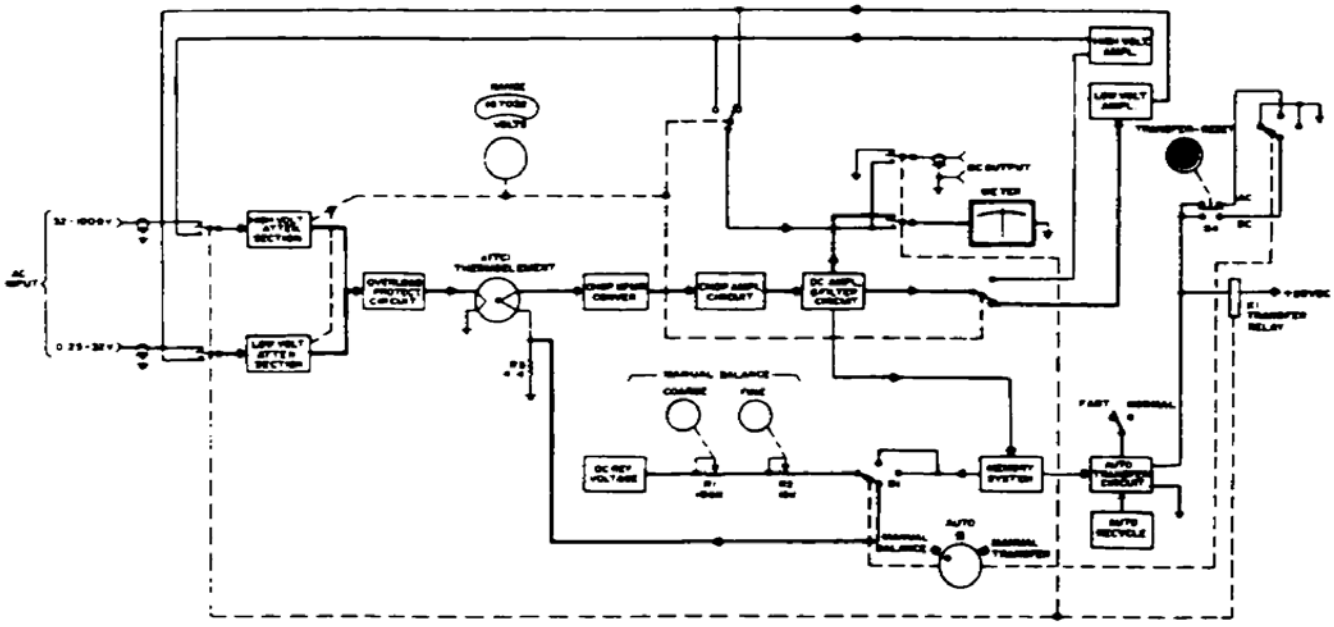


Figure 3-6. Model 1600A block diagram

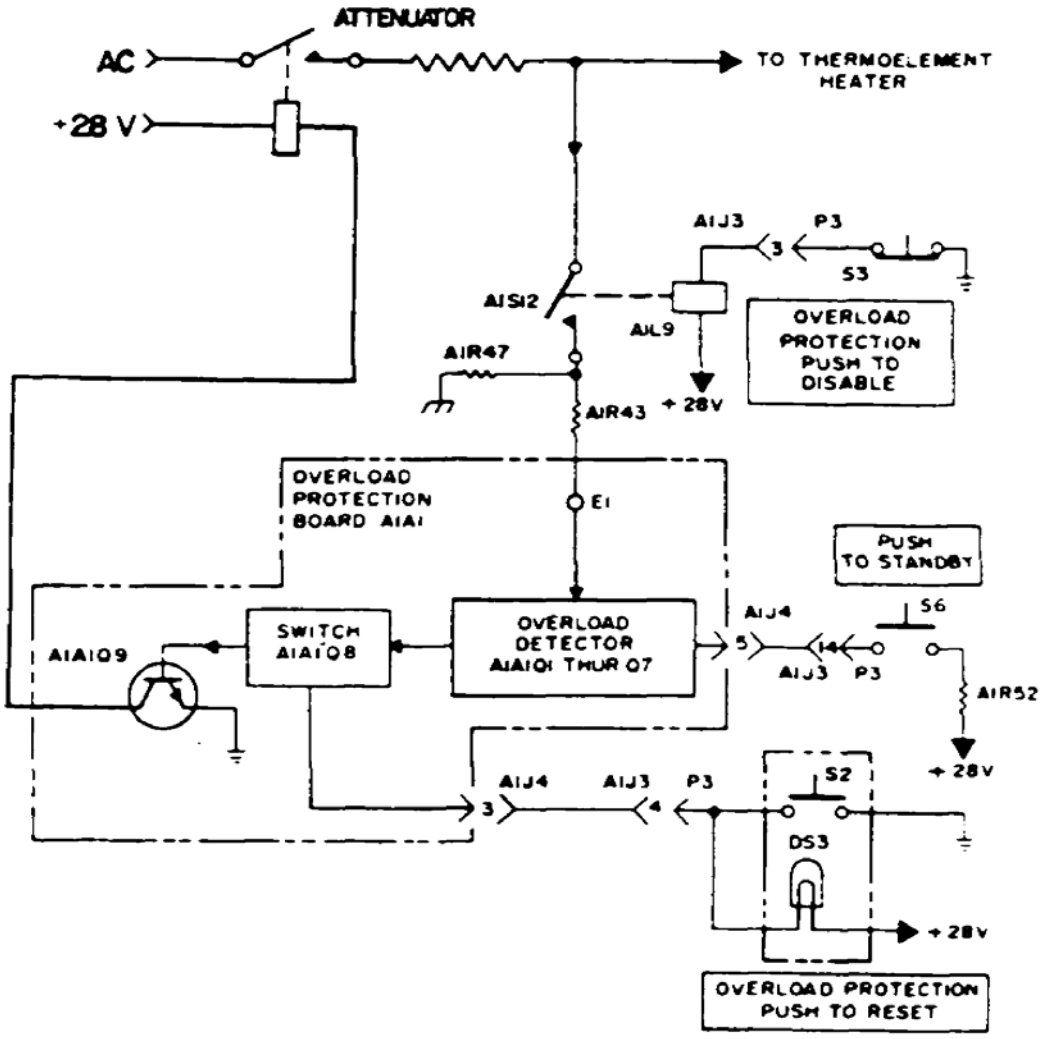


Figure 3-7. Model 1600A simplified input circuitry

2. When the mode selector switch is set to MANUAL BALANCE and the AC indicator is illuminated, the operator adjusts the settings of the MANUAL BALANCE COARSE and MANUAL BALANCE FINE controls until the voltage at the input to the chopper is 0 volts. At this point, the front panel indicates a null. When the operator momentarily depresses the TRANSFER-RESET pushbutton switch, the DC indicator illuminates and the output of either the low or high voltage amplifier is coupled to the same attenuator and the applied AC signal under measurement is disconnected. Since the output of the applicable voltage amplifier was 0 volts at the moment of transfer, the thermoelement output will decrease immediately after the transfer. This results in the generation of an error voltage which is fed to the chopper. The polarity of this error is such as to cause the amplifier to drive the thermoelement so that the error voltage is reduced to zero. At this time the DC output of the voltage amplifier, which is present at the DC OUTPUT binding posts, is equal to the RMS value of the applied AC signal.

3. When the mode selector switch is set to AUTO, the AC indicator illuminates and the AC signal under measurement is coupled to the thermoelement in the same manner as for manual balance operation. The DC output of the thermoelement is chopped, amplified, and applied to a memory circuit which automatically develops a DC voltage which balances the thermoelement output. At this point, the voltage amplifier output is 0 volts and the meter indicates a null. After a short delay interval, the transfer circuitry is automatically triggered and the output of the voltage amplifier is coupled to the attenuator and the applied AC signal is disconnected. The resulting action is identical to the manual transfer mode. An automatic periodic recycle mode from DC to AC is switch selectable. This recycle mode acts as an auto zero circuit to minimize the effects of thermal drift.

4. The manual transfer mode is virtually identical to the automatic transfer mode except that the transfer is accomplished by depression of the TRANSFER-RESET pushbutton switch instead of being automatic.

Learning Event 4:
DESCRIBE THE NBS THERMAL VOLTAGE CONVERTER SET

1. The NBS Thermal Voltage Converter (TVC) set, shown in Figure 3-8, consists of three instruments which are used as a standard source of known RF voltages in the frequency range of 100 MHz to 1 GHz. The TVCs are rated at 0.25 -1 volt, 1-2.4 volts, and 2.4-7 volts. They can be used to accurately calibrate any type of voltmeter that can be attached to their output. A device that can detect the output of a thermocouple is needed to operate the instruments.

2. Each instrument consists of a frequency-compensated thermocouple with a "T" connector built in. The basic diagram is shown in Figure 3-9. The RF voltage is measured at the reference plane indicated. This place coincides with the end of a type "N" female connector screwed into the standard output. This RF voltage is detected by the TVC which is made up of a thermoelement (TE), a dropping resistor (R), and a compensation network (Rc and Cc). The voltage at the voltage reference plane is dropped across R and the heater of the thermoelement. The thermocouple output of the TE is a function of the voltage drop across its heater and the reference voltage.

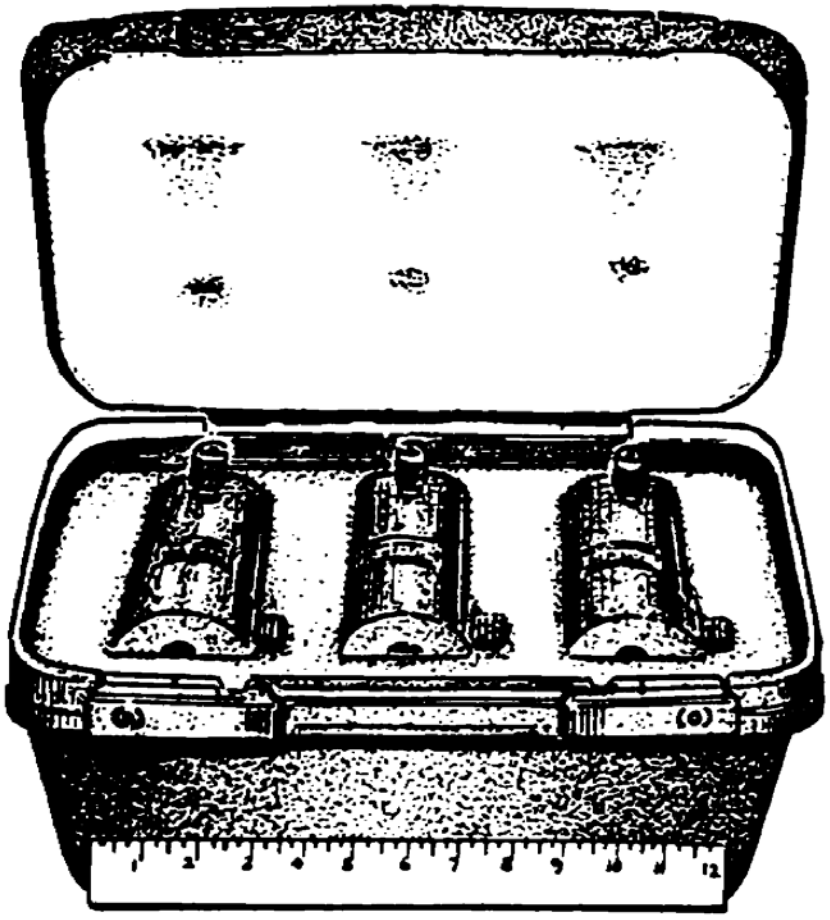


Figure 3-8. NBS TVC set

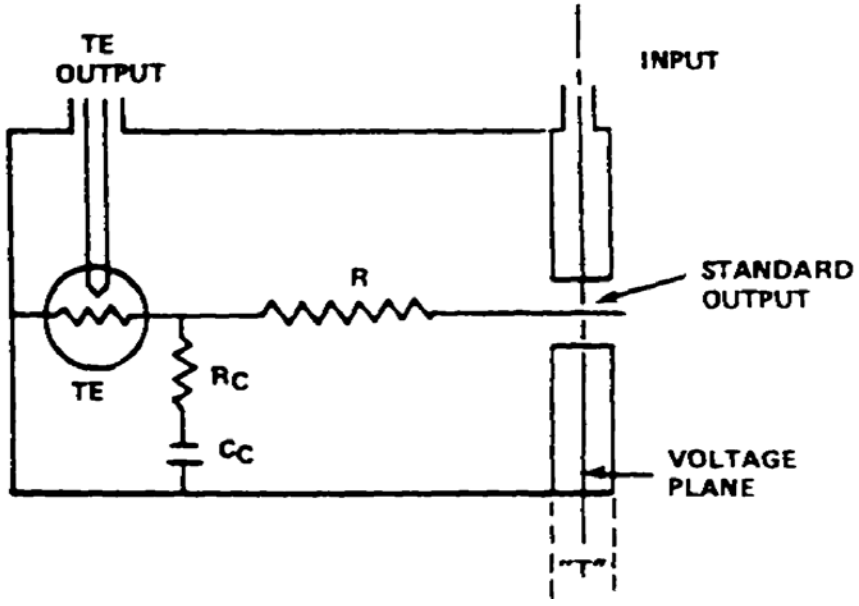


Figure 3-9. TVC circuit

3. The RF-DC difference technique is used in the operation of these units. This technique consists of measuring the percent difference between the RF output when RF is applied and the DC output when DC is applied for the same TE output. This difference is not a function of temperature or level.

4. The compensating network made up of Rc and Cc is used to maintain the RF-DC difference within 20 percent over the entire frequency range up to 1 GHz. The actual RF-DC difference is determined by comparison with the national reference standard.

Lesson 3
PRACTICE EXERCISE

1. Which Model 1600A mode permits the highest accuracy measurements of signals as slow as 2 Hz?

   a. Manual transfer
   b. Manual balance
   c. Auto
   d. All the above

2. When using external thermal converters, how many seconds are allowed for the DC loop to stabilize?

   a. 25 to 30
   b. 20 to 25
   c. 15 to 20
   d. 10 to 15

3. How many steps are there in operating the 1600 in manual balance?

   a. 5
   b. 6
   c. 7
   d. 8

4. When doing reverse manual balance operation, which of the following is NOT true?

   a. Mode switch to auto balance
   b. Warm-up time is 20 minutes
   c. Range volts switch to desired range
   d. Couple ATS to line power

5. In automatic balance operation, the meter pointer will deflect to ZERO on the BAL scale after _____?

   a. 10 seconds
   b. 15 seconds
   c. 20 seconds
   d. 25 seconds

6. What feature on the 1600A permits presetting a differential voltmeter or potentiometer?

   a. TIMES METER READING dial
   b. BAL scale
   c. TRANSFER RESET pushbutton switch
   d. X5 NULL pushbutton

7. It is advisable to read the DC transfer voltage on a _____-second basis?

   a. 10
   b. 15
   c. 20
   d. 25

8. Which mode/modes should be used to measure moderately unstable input signals?

   a. Manual balance
   b. Automatic
   c. Manual transfer
   d. Either a or b

9. What is the maximum voltage which may be safely applied to the Model 1600A Thermoelement Heater?

   a. 0.045 Vrms
   b. 0.45 Vrms
   c. 4.6 Vrms
   d. 45 Vrms

10. What range of voltages may be measured with the NBS TVC set?

    a. 0.25 - 1 V
    b. 0.25 - 2.4 V
    c. 0.25 - 7 V
    d. 2.5 - 7 V

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ANSWERS TO PRACTICE EXERCISES

Lesson 1

1.	d	Learning Event 1	para 2	pg 1
2.	a	Learning Event 1	para 2	pg 1
3.	d	Learning Event 1	para 5	pg 3
4.	b	Learning Event 3	para 1b	pg 9
5.	a	Learning Event 3	para 3c(2)	pg 11
6.	c	Learning Event 2	para 1	pg 4
7.	c	Learning Event 2	para 1c	pg 4
8.	b	Learning Event 3	para 4b	pg 12
9.	d	Learning Event 2	para 6a(2)	pg 7
10.	b	Learning Event 2	para 6b(1)	pg 8

Lesson 2

1.	b	Learning Event 1	para 1	pg 16
2.	d	Learning Event 1	para 3d(1)	pg 20
3.	c	Learning Event 1	para 3o	pg 30
4.	b	Learning Event 1	para 3	pg 17
5.	c	Learning Event 1	para 3n(1)	pg 29
6.	d	Learning Event 1	para 3b	pg 18
7.	a	Learning Event 2	para 4	pg 34
8.	c	Learning Event 1	para 3c(9)	pg 19
9.	a	Learning Event 2	Table 2-1	pg 33
10.	a	Learning Event 3	para 1	pg 36

Lesson 3

1.	b	Learning Event 1	para 3	pg 41
2.	d	Learning Event 2	para 5	pg 54
3.	d	Learning Event 2	para 1	pg 50
4.	a	Learning Event 2	para 2b	pg 52
5.	b	Learning Event 2	para 3f	pg 53
6.	a	Learning Event 2	para 4f	pg 53
7.	b	Learning Event 1	para 4e(4)	pg 48
8.	c	Learning Event 1	para 4f	pg 49
9.	b	Learning Event 3	para 1	pg 55
10.	c	Learning Event 4	para 1	pg 57